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Occurrence, Density, and Distribution of the Larvae of Three Commercially Important Crab Species in the Florida Current off the Southeast Coast of Florida, U.S.

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Namaste.

Abstract

Knowledge of the temporal and spatial distribution and density of the larvae of Florida's commercially important crab species, the blue crab, *Callinectes sapidus*, the golden crab, *Chaceon fenneri,* and the stone crab, *Menippe mercenaria* in the nearshore and offshore waters of Florida's southeast coast is minimal. Such data, however, can be crucial to our understanding of the population dynamics of these vital fishery species. To obtain baseline data of the occurrence and distribution of these species' larvae in the Florida Current, densities were obtained from zooplankton tows from an E-W transect northeast of Port Everglades, Ft. Lauderdale, Florida along the inshore edge of the Florida Current during the months of February, March, April, May, July, September, and November of 2007. Results showed that densities of *C. sapidus* and *C. fenneri* were much lower than expected over the course of the sampling period though peak density patterns were seen for all species. Statistical analysis was not possible for *C. fenneri* and *M. mercenaria* due to their extremely low densities from the samples. However, peaks in larval density from all three species were seen to coincide with known peak spawning periods. Minimal occurrence for *M. mercenaria* was not unexpected as this species has not been observed to use the major ocean currents as a dispersal mechanism. Low densities of *C. fenneri*, however, were unexpected as adult females of this species ascend the slope to shallower depths to release eggs. This migration to shallower depths would position them directly within the flow of the Florida Current making it highly likely that their larvae would be collected in the water column from this area. However, this was not observed from this study's samples. *C. sapidus* was observed to have the highest densities of all three species although only the megalopa stage and no zoeal stage individuals were identified. *C. sapidus* megalops occurred during all months except April with a peak density in May. Results confirmed a year-round spawning of *C. sapidus* in southeast Florida with peak spawning in the spring and a smaller peak in late summer. It is concluded that none of the species observed utilize the Florida Current as a means of long distance dispersal. Regarding *C. sapidus* especially, it is presumed that local recruitment plays an important role in population enhancement. For the larvae of *M. mercenaria,* however, it is thought that those individuals caught in the strong currents are likely occurring accidentally and lost from parent populations. Expanding sampling and study area and of the physical processes of the nearshore and offshore waters of southeast Florida will help shed light on the dispersal and recruitment patterns for these species. It is with this information that managers have the necessary tools for maintaining sustainable fisheries.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Background

Florida's waters are inhabited by three commercially fished crab species of economic importance; the blue crab (*Callinectes sapidus),* the golden crab *(Chaceon fenneri),* and the stone crab (*Menippe mercenaria).* Studies of their life history, planktonic phase, and settlement as juveniles in the Atlantic waters off Florida's southeast coast, however, is minimal. Knowledge of the growth, dispersal and settlement for any species is of ecological importance, and vital for a commercially important species and the management of its fisheries. All three commercially fished crab species in southeast Florida are actively managed. Yet, while *Callinectes sapidus* is heavily researched throughout Delaware Bay, Chesapeake Bay, and in the North Carolina estuaries (Dittel and Epifanio 1982; Mc Conaugha et al. 1983; Epifanio 1995; Forward et al. 2003), and although multiple studies exist for *Menippe mercenaria* and *Chaceon fenneri* from the Gulf of Mexico (Lockhart et al. 1990; Perry et al. 1991; Muller et al. 2006), research of their life histories is either insufficient or lacking for their populations on the southeastern coast of Florida.

Many species with a planktonic stage exhibit similar life history patterns (Shanks 1995) but their behavior can differ with the differing ecosystems they inhabit. For instance, *C. sapidus*, an estuarine crab, exhibits a similar planktonic larval development over the continental shelf as its conspecifics along the Atlantic Coast of the United States (Shanks 1995). However, the ecological differences from Florida's Biscayne Bay to the Chesapeake Bay can affect how a return to estuaries by larval transport occurs between the ecosystems. Also markedly different along the southeast Florida coastline is the

narrow continental shelf and the close proximity of the Florida Current (FC) to shore which can impact a local species' relationship to its environment. For instance, in contrast to more northern populations of *C. sapidus*, those from southeastern Florida would not have as far to travel in order to reach the Florida Current.

Investigation of these different factors can provide important insight into a species' role in its environment, and without sufficient data relating a species to its ecosystem, determining sustainability is difficult and effective management suffers. Even this basic understanding is lacking in southeast Florida. Therefore, this study seeks to gather baseline data of these commercially important species to determine larval occurrence and distribution in the offshore waters of the southeast Atlantic Coast. With this information, it is hoped to infer possible rates and routes of movement into and out of parent populations.

Throughout this work, the use of the word "larva/ae" will be used to include all crustacean stages prior to settlement as juveniles. "Zoea" will refer to any planktonic stage after hatching but prior to the "megalopa/ps" stage, the final larval stage before metamorphosis to the juvenile stage.

1.2 The Planktonic Life

Species with a planktonic larval phase display similar life history patterns including such behaviors as female migration for spawning, hatching of eggs and development through several stages in the plankton over the continental shelf, settlement as juveniles, and subsequent transport back to parent populations. This planktonic phase is believed to be an adaptation ensuring long-distance dispersal and genetic diversity which offer several evolutionary advantages. First, it is thought that the females migrate

away from parent populations as a means of separating the larvae from predators (Shanks 1995). This female migration to the mouths of estuaries generally occurs during the nocturnal high tide and ensures the eggs are carried offshore upon release (Reyns and Sponaugle 1999). Second, in addition to the dispersal advantages associated with vertical placement in the water column, larvae can also avoid predators with this active movement by sinking into the darker, deeper waters (Cronin and Forward Jr. 1986). Third, length of larval development and time spent in the plankton can determine dispersal distances (Mc Conaugha et al. 1983; Sulkin and Heukelem 1986; Havenhand 1995). An example of a long planktonic phase is found in the Caribbean spiny lobster, *Panulirus argus*, whose larvae spend from six months to a year in the plankton (Acosta et al. 1997). The three commercial species of crab in Florida, though they don't possess the long plankton phase of *P. argus*, do exhibit long planktonic phases, spending anywhere from 25 to 60 days in the plankton (Costlow and Bookhout 1959; Porter 1960; Stuck et al. 1992).

Though this long planktonic phase can aid in long-distance dispersal, current research shows that many brachyuran species may not disperse the long distances previously assumed (Mc Conaugha 1992). Once thought to be at the mercy of the currents and tides, brachyuran crab larvae are now known to exhibit active movement in the water column as a means of controlling their fate in these currents (Epifanio 1988a; Shanks 1995). However, even larvae that display active horizontal swimming are likely not able to swim against tides and currents (Shanks 1995). It has been shown that larvae actively control their position vertically in the water column, a behavior that allows them

optimal placement in the water column for catching tidal flows and currents leading to more local retention, especially for estuarine species (Shanks 1995; Forward et al. 1996).

1.3 Dispersal or Retention

Long-distance larval dispersal provides a beneficial means of genetic exchange and colonization of new populations for species with a planktonic phase and has been studied in great depth throughout the world's oceans (Mc Conaugha 1992; Havenhand 1995). The physical processes by which larvae are either dispersed or locally retained and recruited back to parent populations are considered by some researchers to be the most important mechanisms for ensuring a sustainable fishery (Acosta et al. 1997; Horwood et al. 2000). Major oceanic processes, for example, the currents and tides, play an important role in this dispersal. The Loop Current in the Gulf of Mexico and the Florida Current, which travels through the Florida Straits and up the east coast of Florida, eventually meet up with the Gulf Stream to make up the local currents system. Tides, and other processes of the major currents act to disperse and/or retain planktonic larvae (Kennedy and Barber 1981; Pitts 1999; Sponaugle et al. 2005) and aid in genetic exchange through long-distance dispersal or, alternatively, act to locally retain larvae (Epifanio 1988a). The Florida Current and associated processes such as eddies, warm core rings, and countercurrents (Wang and Mooers 1998; Soloviev et al. 2003), play a crucial role in larval transport into and out of parent populations (Hare et al. 2002).

An understanding of the development and life history of the larvae in these currents is essential in determining these dispersal and recruitment patterns. For example, a study by Porch (1998) modeled larval fish dispersal and found that the Florida

Current will sweep the majority of larvae away from parent populations unless they are entrained in and transported shoreward by gyres, or nearshore eddies. Further, a field study of the estuarine crab, *Rhithroanopeus harrissii*, showed that 25% of its larvae were retained in the area of spawning by the time they reached the megalopa stage concluding that active vertical migration by the larvae played a major role in this retention (Cronin 1982). In contrast, if larvae fail to be retained in this manner they may be transported too far from any physical mechanism to be recruited and are lost from the populations altogether (Shanks 1995).

Traditional theories of larvae being at the mercy of the currents have been replaced by theories of active vertical migration in the water column (Epifanio 1988b). This vertical movement is thought to be in response to physical cues (salinity and temperature changes, lunar and diel cycles, etc.), which places the larvae optimally in the water column for transport into and out of parent populations (Epifanio 1988b; Tankersley et al. 1995). Ebb and flood tides are an important mechanism of this transport, particularly for estuarine crabs, and have been examined as the transport mechanism by which early stage larvae exit an estuary and by which late stage larvae reenter the estuary (Olmi 1994; Forward et al. 1996; Forward et al. 1997).

For many estuarine crabs, early stage larvae must position themselves to be swept offshore for development on the continental shelf, and late stage larvae, the megalops, must be transported shoreward toward the estuaries and then up the estuary for settlement as juveniles (Dittel and Epifanio 1982; Shanks 1995; Forward et al. 1996). Forward et al. (1996) found that the megalops follow different cues offshore than when nearshore or within the estuaries. In a follow up study, Forward et al. (1997) found the megalops to

reside in the neuston layer offshore but in the water column when within the estuary. Their study showed that the megalops follow light cues offshore, positioning themselves in the surface layers during the day, but respond to salinity changes when within the estuary, placing them within the water column at night during flood tides.

1.4 Management Implications

Successful management of a sustainable fishery requires knowledge of a species' biology, in particular, their larval dispersal and retention capabilities, mortality, and subsequent recruitment back to parent populations. This final stage, recruitment back to parent populations, along with survival to adulthood, is the only successful means of stock enhancement (Mc Conaugha 1992; Horwood et al. 2000). In fact, many researchers believe that sustainability cannot be achieved if these factors are poorly understood (Sandoz and Rogers 1944; Jamieson 1986; Porch 1998; Horwood et al. 2000; Grantham et al. 2003). Traditional management for fishery sustainability focuses on gear restrictions, seasonal closings, quotas, etc (Ault et al. 2005). Utilizing such mechanisms as recruitment models to forecast the number of new recruits into a fishery can be a useful tool in more accurately predicting measures such as maximum sustainable yield (MSY) (Jamieson 1986).

Without these accurate predictions, future changes to management cannot be effective at successfully achieving sustainability. Unfortunately, for many species, this is just the case. For the commercially important crab fisheries in southeast Florida, there are little data on their larval dispersal and whether they exhibit long-distance dispersal utilizing the Florida Current, whether they are being locally retained, or whether local

stock populations are being seeded from neighboring populations whose larva are dispersing though the local current system.

2.0 Project Overview

The goal of this study is to identify occurrence and densities of the larvae of *Callinectes sapidus*, *Chaceon fenneri, and Menippe mercenaria* relative to the Florida Current (FC) and to compare any distributional differences between inshore and offshore areas relative to the FC. With this information, dispersal and recruitment may be inferred and conclusions drawn as to whether larvae are using the current to disperse to other habitats and/or whether local retention plays more of a role in population enhancement. This baseline data will be gathered as a means of filling in missing information about these species' larval phase in this region.

The objectives of this study aim to answer several questions: 1) Are there occurrences of *C. fenneri, C. sapidus* and *M. mercenaria* larvae throughout all sampling months? 2) Does each species show a peak in density corresponding to seasonal spawning? 3) Is the estuarine species, *C. sapidus*, found in higher density than the nearshore species, *M. mercenaria*, or the deepwater species, *C. fenneri*? 4) Is there a difference in larval density between nearshore and offshore locations?

Each species investigated in this study inhabits a different ecosystem and exhibits different behaviors related to those ecosystems. Each, therefore, is being treated separately in this document. An overall methodology section follows this introduction covering the methods used during sample collection. Following are three sections discussing each species' biology and role in the plankton, identification methodology,

and discussions of each species analysis and results. Lastly, an overall conclusion will sum up the three individual studies. Appendices A – E compare densities of all three species per month, net type, station, diel period, and depth.

3.0 Materials and Methods

3.1 Overall Methodology

Zooplankton tows were conducted aboard the R/V *F. G. Walton Smith* in 2007 along an E-W transect northeast of Fort Lauderdale, Florida during the months of February, March, April, May, July, September, and November. Sampling was conducted along the western edge of the Florida Current at 3 stations: Station A (inshore); 80.03°W – 26.2°N, Station B (middle); 79.97°W – 26.2°N, Station C (offshore); 79.91˚W – 26.18˚N (Figure 1).

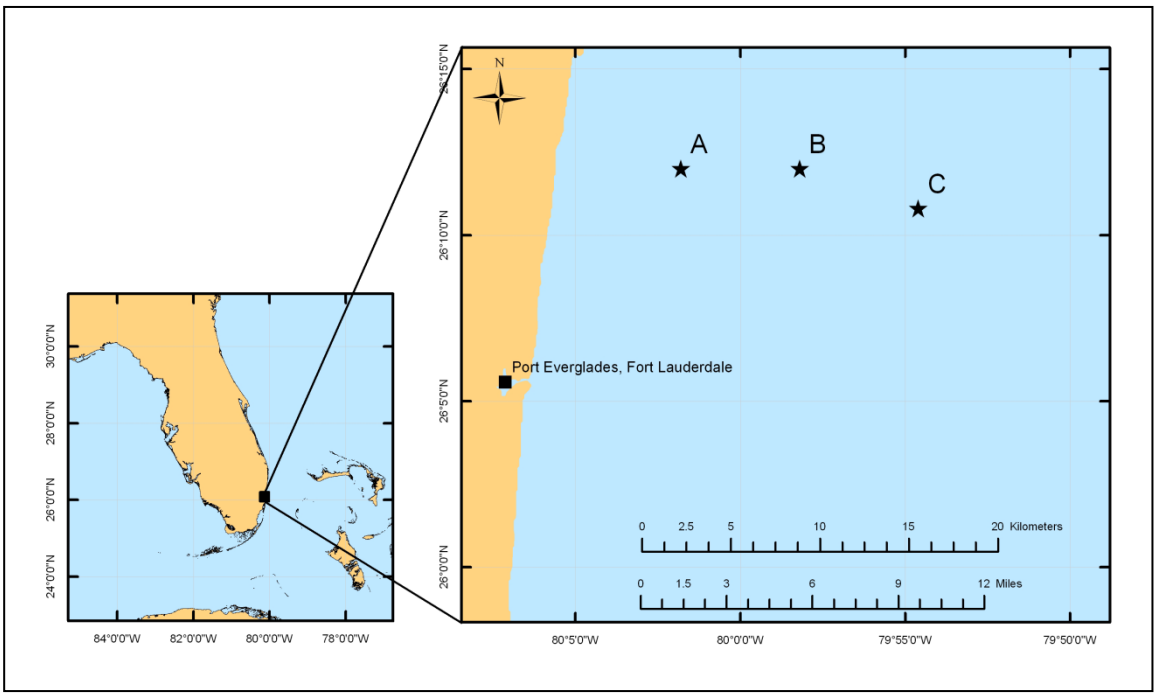


Figure 1: Sampling stations along and E-W transect in the Florida Current. A = inshore, B = middle, C = offshore.

3.2 Sampling Methodology

Water samples were collected using a 0.61 m diameter bongo net outfitted with 202 µm mesh, and a 1 m x 1.4 m multiple net mid-water Tucker trawl outfitted with 760 µm mesh. The bongo net was deployed from 0 – 25 m and 0 – 200 m for 15 minute durations at each depth range. The Tucker trawl net A sampled the water column from 0 – 25 m, net B sampled 25 m – 200 m, and net C from 200 m to the surface. Nets A and B only were analyzed for this study. Each Tucker net remained open for 10 minutes at each respective depth range. At station A, the most nearshore station, depths become shallower as the slope rises and nets at this station were deployed to a depth of 150 m. Deployment rates for a winch wire angle of 45° during deployment were as follows:

Tucker trawl 25 m: 3.5 m/min.; Tucker trawl 200 m: 35 m/min; bongo 25 m: 5 m/min; bongo 200 m: 55 m/min. Rates were adjusted for slack currents. A General Oceanics mechanical flowmeter was attached to the opening of each net to record water volume.

Continuous sampling occurred over a 24-hour period with day and night sampling conducted at stations A and B and daytime sampling only at station C. Samples were preserved at sea in 5% seawater-buffered formalin. Samples were split using a Folsom plankton sample splitter and transferred into a solution of 70% ethyl alcohol for long-term preservation. One-quarter of each sample was analyzed for this study, one-quarter was analyzed for commercially important fish species at the Florida Institute of Technology and one-half of each sample was archived. Volume of water (m^3) from each net was calculated from flow meter readings using the following calculation:

[(flowmeter count difference * 26,873)/999999] * [3.14 * net diameter)^2]/4

Identification of specimens was conducted using an Olympus SZX7 stereomicroscope fitted with a 1.5x objective. Imaging and measurements of individuals were done using a 3.3 MPX camera attached to the microscope and transferred to a PC with Rincon Image Analysis Software.

3.3 Physical Data Collection

Acoustic Doppler Current Profiler (ADCP) data along with conductivity-temperature-depth (CTD) profiler data were collected during each sampling period. Data from a shipboard ADCP collected data on the current magnitude and direction throughout

the sampling period. An Idronaut Ocean Seven 304 CTD logger, attached to the net frames, collected data on depth, salinity and temperature during each tow. CTD data were only collected during February, July, September and November.

4.0 *Callinectes sapidus* (Blue Crab)

4.1 Introduction

Blue crab harvests make up the largest crab fishery and the second largest crustacean fishery in the United States (NMFS 2008). In Florida, the fishery boasts similar statistics reporting the highest landings of all crab fisheries and the second highest for all crustacean fisheries in the state (FFWCC 2010). Due to this high profile and great economic value, numerous research efforts exist for this species, mostly concentrated in the Mid-Atlantic States. Little is known, however, of the recruitment patterns of spawned blue crabs and their effects on stock population enhancement to the local Florida populations (Murphy et al. 2007). With this information, managers can help maximize the sustainability of the populations.

4.1.1 Florida Fishery

Management for the blue crab fishery in Florida began in 1941 with the implementation of capture limits based on a minimum carapace width (CW) of 5 ½ inches and a restriction on the harvest of females carrying eggs. Regulations went through numerous revisions until 1993 when a renewed management plan was implemented. The fishery today is managed by the Florida Fish and Wildlife Conservation Commission which manages the state-wide population as a whole but separates the fishery into two stocks, the Gulf stock and the Atlantic stock, for reporting purposes (Steele and Bert 1998; Murphy et al. 2007). The Atlantic fishery comprises the counties from Miami-Dade on the southeastern tip of Florida through Nassau County on the northeastern border of the state. Both recreational and commercial fisheries exist in Florida and though the recreational fishery is assumed to contribute heavily to overall

landings, little data is available to support this. Current regulations to the fishery include: licensing, protection of gravid females, minimum size limit, allowable gear types, bag limits for those recreationally caught, and catch limits per trip, as well as many others. Harvesting is permitted year-round with the exception of closures in the Gulf fishery for any harvesting done between three and nine miles offshore from September 20 to October 4 each year. In addition, a new 10-day closure for the trap fishery has been implemented on a rotating basis in all counties to gather lost traps (Murphy et al. 2007).

The commercial fishery for Florida blue crab began in the late 1800s and remained locally distributed until 1930 (Steele and Bert 1998). Today, the commercial catch in Florida makes up the 4th largest fishery in the state (FFWCC 2010). Harvesting of blue crabs utilizing traps was introduced in Florida in the early 1950s and was followed by a marked increase in landings. Both hard and soft shell (recently molted) blue crabs are harvested (Steele and Bert 1998).

As of the preliminary 2009 landings data, blue crab makes up 6% of total fisheries landings in the state of Florida and 4% of total blue crab fishery landings in the United States totaling 155.3 million pounds (mp) in 2008 (NMFS 2008). Over 4 1/2 mp of blue crab come from Florida state waters with 1.5 mp of that total from the Atlantic fishery. An overall decline in landings has been seen in the Florida fishery since its peak in 1965 when annual landings reached 27 mp (Steele and Bert 1998). Analyses of data from the 2002 to 2005 seasons do not show evidence of overfishing even with fluctuating harvests. This indicates increasing population sizes but a resilience of blue crabs to high fishing pressure (Murphy et al. 2007). Management of the fishery is currently classified as preventative (Steele and Bert 1998; Murphy et al. 2001).

4.1.2 Life History

Callinectes sapidus is a brachyuran crab from the family Portunidae. It is an estuarine crab inhabiting nearshore and estuarine ecosystems along the east coast of North and South America from Massachusetts to Argentina and in the Gulf of Mexico (Steele and Bert 1994; Murphy et al. 2001). Adults have a short life span of 2 to 4 years (Tagatz 1968; Steele and Bert 1994) and are typically found in brackish and low salinity waters while their larvae require salinities greater than 22 ppt, for survival (Murphy et al. 2001). The larvae develop in the higher salinity waters over the continental shelf before settling as juveniles back into the estuaries. The females are catadromous, travelling to the mouths of estuaries to release their eggs while the males remain in the low salinity estuaries their entire adult lives (Tagatz 1968; Steele and Bert 1994).

Females mate only once in their lifetime (Tagatz 1968; Murphy et al. 2001) and can retain sperm for one year, using it for one or several spawning events, and can produce 1 to 2 million eggs at a time. Spawning season varies with latitude as well as habitat and appears to be delayed until water temperatures increase to an optimum level (Tagatz 1968). In higher latitude waters, spawning occurs in the summer months with a peak in July (Mc Conaugha et al. 1983) and farther south in Carolina waters, spawning has been observed from April to August with a peak in July and August (Steele and Bert 1994; Goldman 2007). Along the Atlantic Coast of Florida, spawning is observed year round with a peak in spring and summer months (Nichols and Keney 1963; Tagatz 1968). Researchers have found different spawning seasons from the Gulf stocks compared to the Atlantic stocks in Florida. Steele and Bert (1994), for instance, reported a spawning season in Tampa Bay from March to September while Tagatz (1968) observed a longer

spawning season in the St. Johns River that began in February and continued through October. There are no available data for the southeastern coast of Florida.

After spawning, larvae are hatched at the mouths of estuaries where they are transported by currents to the continental shelf (Mc Conaugha 1992). After hatching, seven zoeal stages develop over approximately 30 – 60 days at which time the megalopa develops during another 1 to 2 week period (Costlow and Bookhout 1959; Mc Conaugha 1992; Epifanio and Garvine 2001; Murphy et al. 2001). Development times vary with varying water temperatures and are lengthened at temperatures below 25˚ C (Stuck and Perry 1982). The megalopa develop into juveniles that return to the estuary and settle into adult populations (Tagatz 1968; Murphy et al. 2007).

4.1.3 Estuary ⇆ Shelf Transport

Two major estuaries along the South Atlantic Coast of Florida are the Indian River Lagoon in Brevard County and Biscayne Bay in Miami-Dade County. Both contribute substantially to the overall landings from the Atlantic Coast stock with reported 2009 preliminary landings of 43,563 pounds for Miami Dade County and Brevard County reporting 396,701 pounds (FFWCC 2010). While these numbers indicate that the Indian River Lagoon population is highly productive, there is little current research on recruitment and stock structures in this area. Larval dispersal in estuarine systems is researched in depth in the Chesapeake Bay, Delaware Bay, and in the North Carolina estuaries and, although the estuarine systems of southeast Florida differ, current research can be applied to these systems.

The challenge for estuarine crabs is to reach the higher salinity waters of the continental shelf and to ensure return back to the lower salinity estuaries using physical

processes like eddies and tidal flows. Recent research on estuarine species has focused on the mechanisms available to the larvae that aid in this transport (Epifanio and Garvine 2001; Forward et al. 2003; López-Duarte and Tankersley 2007; Epifanio and Tilburg 2008). While some species of estuarine crab exhibit self-entrainment within the estuary using a rising and sinking movement to avoid being transported offshore, *C. sapidus* larvae require the high salinity shelf water for development and exhibit just the opposite behavior (Tankersley et al. 1995). It is widely accepted that zoeal transport out of the estuary and onto the shelf is due to their residence of surface waters which transport them offshore by ebb tides (Epifanio and Garvine 2001). For transport back to the estuaries, the megalopa are thought to actively situate themselves within the water column as a way of catching the flood tide into the estuary, known as selective tidal stream transport. Additionally, they can be transported by internal waves or wind-driven circulation (Olmi 1994; Tankersley et al. 1995; Epifanio and Garvine 2001). Environmental cues observed to trigger this active migration include salinity, pressure and temperature, though study results showed only changes in salinity contributed to activated movement of the megalops (Tankersley et al. 1995; Forward et al. 1996).

4.2 Objectives

This portion of the study observed densities of blue crab larvae relative to the proximity of the Florida Current (FC) to the coastline in southeast Florida and hypothesized that blue crab larvae would be found in high densities there. Due to the narrow continental shelf, as the females release eggs, the larvae don't have very far to travel before being entrained in the current. This can have great implications for potential long-distance dispersal during their long planktonic phase. As a result, larvae

could potentially be dispersing northward to the Indian River Lagoon or to more northern estuaries. Alternatively, the larvae could travel on counter currents, displaying a high amount of self-recruitment into southern estuaries like Biscayne Bay or farther south into the Florida Keys. Thus, baseline data showing densities of *C. sapidus* in the Florida Current were gathered as a way to provide these essential, yet lacking, data and to be able to infer possible routes of transport.

4.3 Materials and Methods

4.3.1 Species Identification

Samples were analyzed for occurrence of Portunid crabs which were identified to the lowest taxonomic level possible and larval stage determined using the larval descriptions of Costlow and Bookhout (1959), Bookhout and Costlow (1977), Bullard (2003), Stuck et al. (Unpubl.) and Kurata (1970). Initial identification to genus level was done using key morphological features (Figure 2).

For the zoea, telson spination and maxilliped setation were analyzed first. During all stages of portunid crabs, a lateral spine is present on the outer furca of the telson and for all stages of *Callinectes* spp. except Stage 1, maxilliped 1 bears one setae on segment 3 of the endopod.

To identify megalops to the genus level, number of antennal segments, presence of cornua at the base of the carapace, and chela spination were used. In the megalopa stage, both *Callinectes sapidus* and its congener, *Callinectes simili*, have a total of 11 antennal segments. In addition, all the portunid megalopa possess cornua, spines projecting from the base of the carapace. Lastly, most portunids possess a spine on the

proximal segment of the chela, the basi-ishiopodite, and some species also bear a spine on the carpal segment of the chela. *C. sapidus* and *C. similis* both lack this carpal spine.

For positive identification to the species level, measurements were made using the protocol of Stuck and Truesdale (1988), Stuck et al. (1992) and Ogburn et al. (2010). Total length (TL), carapace length (CL), dorsal spine length (DSL), rostral length (RL), spine tip width (STW) and total spine length (TSL) are some of the most distinguishing morphological features of brachyuran crabs. Measurements of these features were taken and compared to those from the larval descriptions of both *C. sapidus* and *C. similis*. Measurements of DSL, RL, TSL, and TL were collected for the zoea. In the megalopa, spination of the carpal and basi-ischiopodite segments of the chela as well as measurements of the proportion of rostral length to total carapace length (RL/TCL) and the proportion of the length of the proximal segments to distal segments of the antenna were used to identify *Callinectes* spp. to the species level.

Developmental stage determination relied exclusively on maxilliped exopod setation. Throughout zoeal development, maxilliped 1 bears 4 plumose setae in Stage 1, 6 plumose setae in Stage 2, 8 plumose setae in Stage 3, 9-10 plumose setae in Stage 4, 11-12 plumose setae in Stage 5, 12-14 plumose setae in Stage 6, 13-15 plumose setae in Stage 7, and 14-17 plumose setae in Stage 8 (Figure 2) (Costlow and Bookhout 1959; Bookhout and Costlow 1977).

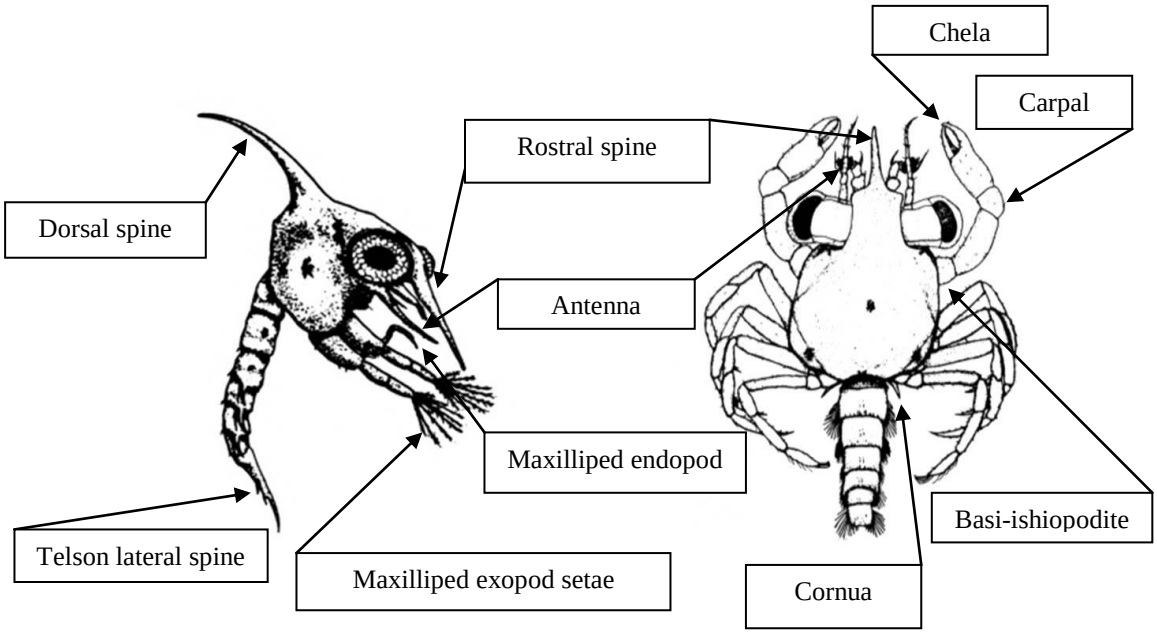


Figure 2: Key Morphological Features of *Callinectes* spp. zoea and megalops. Adapted from Costlow and Bookhout (1959)

4.3.2 Statistical Analysis

Statistical analyses were done using the software package Statistica, StatSoft, Tulsa, OK, USA. A Kolmogorov-Smirnov test was used to determine if the data followed a normal distribution. The result showed a strong significance, ($p<0.01$), indicating that the data are not normally distributed. Therefore, non-parametric tests were used for all analyses. The Mann-Whitney *U* and Kruskal-Wallis tests were used at the $\alpha = 0.05$ level to determine significance.

4.4 Results

4.4.1 Occurrence and Densities

A total of 88 *Callinectes* spp. megalops and 15 zoea larvae of varying stages were identified from all sampling events during the 2007 cruises. Following the method developed by Ogburn et al. (2010), using the combined parameters of the proportion of rostral length (RL) to total carapace length (TCL) (RL/TCL) and the proportion of the length of the distal segments of the antenna to the length of the proximal segments, 42 megalops were confirmed as *Callinectes sapidus*. An additional 19 *C. sapidus* megalops were confirmed using the RL/TCL parameter only, giving a total of 61 confirmed *Callinectes sapidus* megalops (Table 1). All 15 zoea were found to be either *Portunus* spp., *Callinectes similis*, or were not able to be positively identified using the larval descriptions of Bookhout and Costlow (1977).

Table 1: Total *Callinectes* spp. (n) megalops identified per key morphological parameter. RL=rostral length, TCL=total carapace length.

Species	% RL/TCL	Antennal Proportions	% RL/TCL & Antennal Proportions	Confirmed Identification
Callinectes sapidus	1	14	42	61
Callinectes similis	1	17	8	20
Unidentifiable/missing key morphological features	7			7

The majority of megalops came from the May samples making up 54% of total *C. sapidus* megalops. Twenty three percent of megalops were from the July samples, 13% from September, 6.5% were from the February samples, and the March and November samples each made up 1.6% of total *C. sapidus* megalops (Table 2). Though sampling was conducted in the month of April, no *C. sapidus* larvae were identified from those samples and therefore April was excluded from all remaining statistical analyses. Mean densities (1000 m^{-3}) ± 1 standard error of the mean (± 1 SEM) of *C. sapidus* megalops per monthly cruise were highest from the May samples (2.75 ± 1.08). Additionally, station A (inshore) had the highest mean density (1.64 megalops ± 0.53) (Table 2). Density calculations per month, station, net, diel period, and depth category are referenced in Appendices A – E.

Cruise	Total (*n*)	Mean Density ± 1 SEM (1000 m^{-3})	Mean Density ± 1 SEM (1000 m^{-3}) per Station	
February				
	4	0.58 (± 0.28)	0.64 (± 0.51)	St. A
			0.74 (± 0.49)	St. B
			0.00	St. C
March				
	1	0.07(± 0.07)	0.17 (± 0.17)	St. A
			0.00	St. B
			0.00	St. C
May				
	33	2.75(± 1.08)	6.29 (± 2.20)	St. A
			0.59 (± 0.30)	St. B
			0.00	St. C
July				
	14	1.18(± 0.59)	2.23 (± 1.37)	St. A
			0.73(± 0.39)	St. B
			0.00	St. C
September				
	8	0.79(± 0.35)	0.31 (± 0.31)	St. A
			1.43 (± 0.76)	St. B
			0.47 (± 0.47)	St. C
November				
	1	0.07(± 0.07)	0.17 (± 0. 17)	St. A
			0.00	St. B
			0.00	St. C
Entire Year's Sampling				
	61		1.63 (± 0.53)	St. A
			0.58 (± 0.18)	St. B
			0.08 (± 0.08)	St. C

Table 2: Total *C. sapidus* megalops abundance and mean density (1000 m^{-3}) (± 1 SEM) per monthly cruise and per station. Station A = inshore, B = middle, C = offshore.

Monthly Cruise Sampling

Mean density was analyzed for all monthly cruises and found to be significantly different (p=0.0067, Kruskal-Wallis). A further pairwise comparison between monthly sampling events was done to see where the significant differences existed. Significance was found between the sampling events of March and May (p=0.003, Mann-Whitney *U*), March and July (p=0.002, Mann-Whitney *U*), May and November (p=0.025, Mann-Whitney *U*), and July and November (p=0.018, Mann-Whitney *U*) (Figure 3).

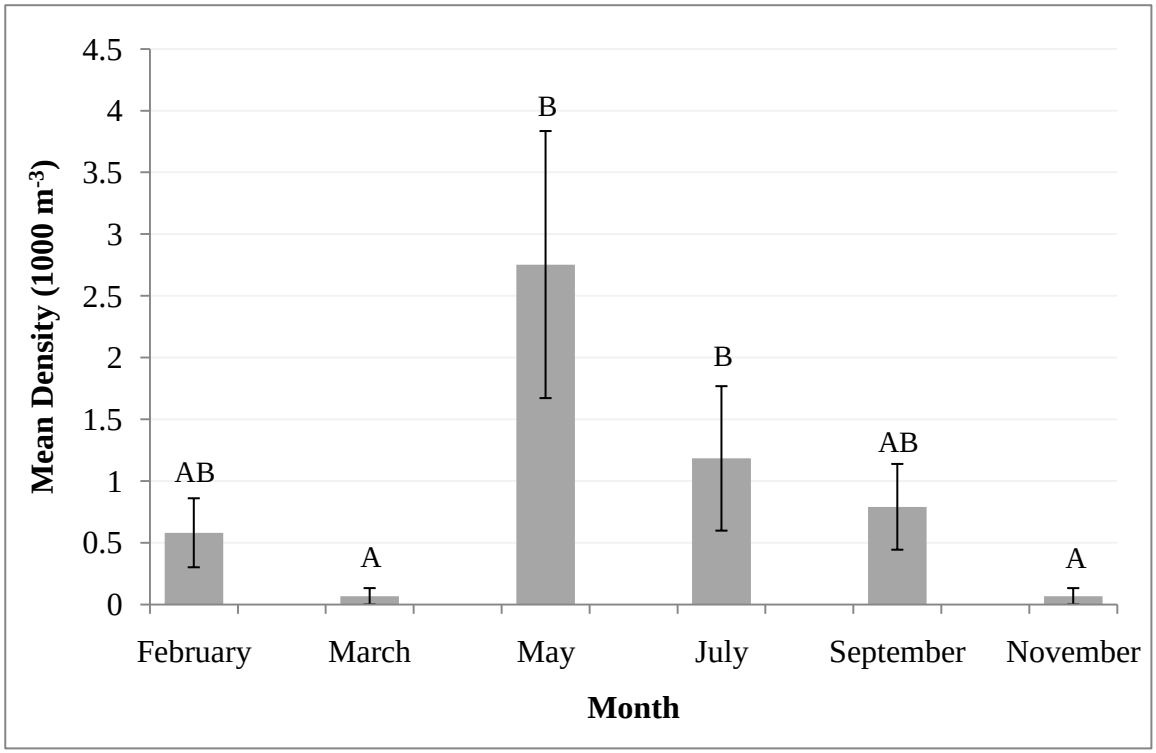


Figure 3: Monthly mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops. Means with different letters indicate a statistical difference (p<0.05: Mann-Whitney *U*).

Net Type

A comparison of net size was done to determine whether a significant difference was present between the densities of *C. sapidus* megalops from the bongo and Tucker trawl net mesh sizes. Overall, there was no significant difference over the entire sampling period (p=0.41, Mann-Whitney *U*) (Figure 4). As there was no difference seen between net mesh size, densities from all nets were combined for all remaining analyses.

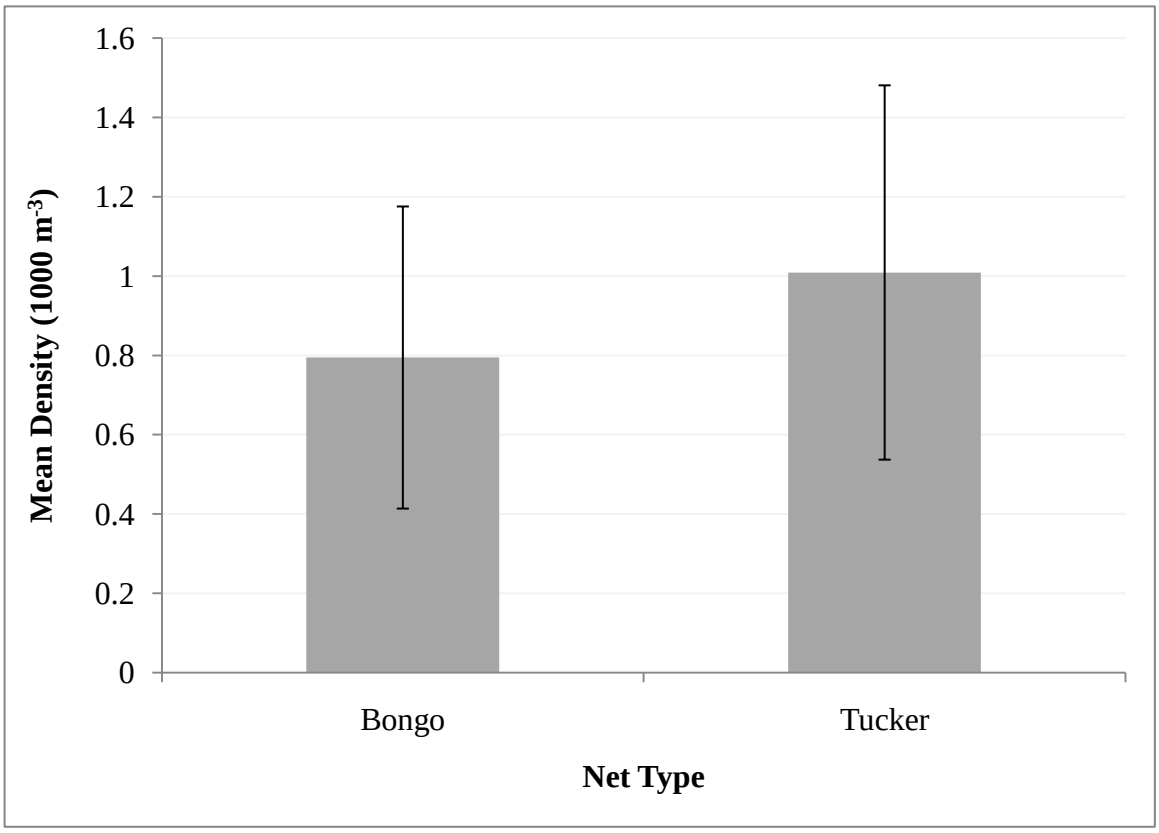


Figure 4: Total mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops across all months by net type shows no significant difference (p>0.05, Mann-Whitney *U*).

Station

When densities of *C. sapidus* megalops at each station were combined for the entire year's sampling period, a significant difference was found (p=0.027, Kruskal-Wallis). A pairwise comparison showed a significant difference between stations A and C (p=0.009, Mann-Whitney *U*) and between stations B and C (p=0.043, Mann-Whitney *U*) (Figure 5).

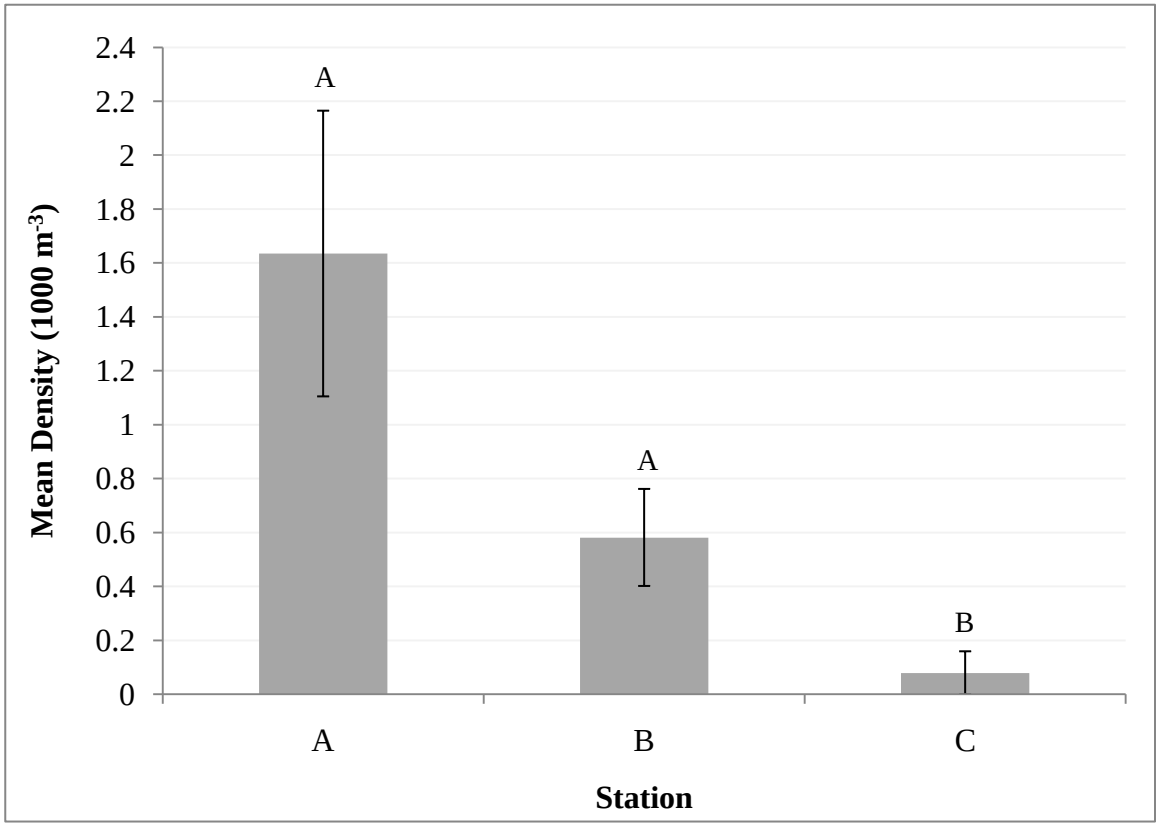


Figure 5: Mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops per station over the entire year's sampling period. Means with different letters indicate a statistical difference (p<0.05: Mann-Whitney *U*).

C. sapidus megalops densities at each station were also compared for each month's sampling event with only the densities from the month of May showing a statistical significance (p=0.015, Kruskal-Wallis). Pairwise comparison of May densities per station returned a significant difference between stations A and B (p=0.025, Mann-Whitney *U*) (Figure 6). All other monthly comparisons showed no significant differences.

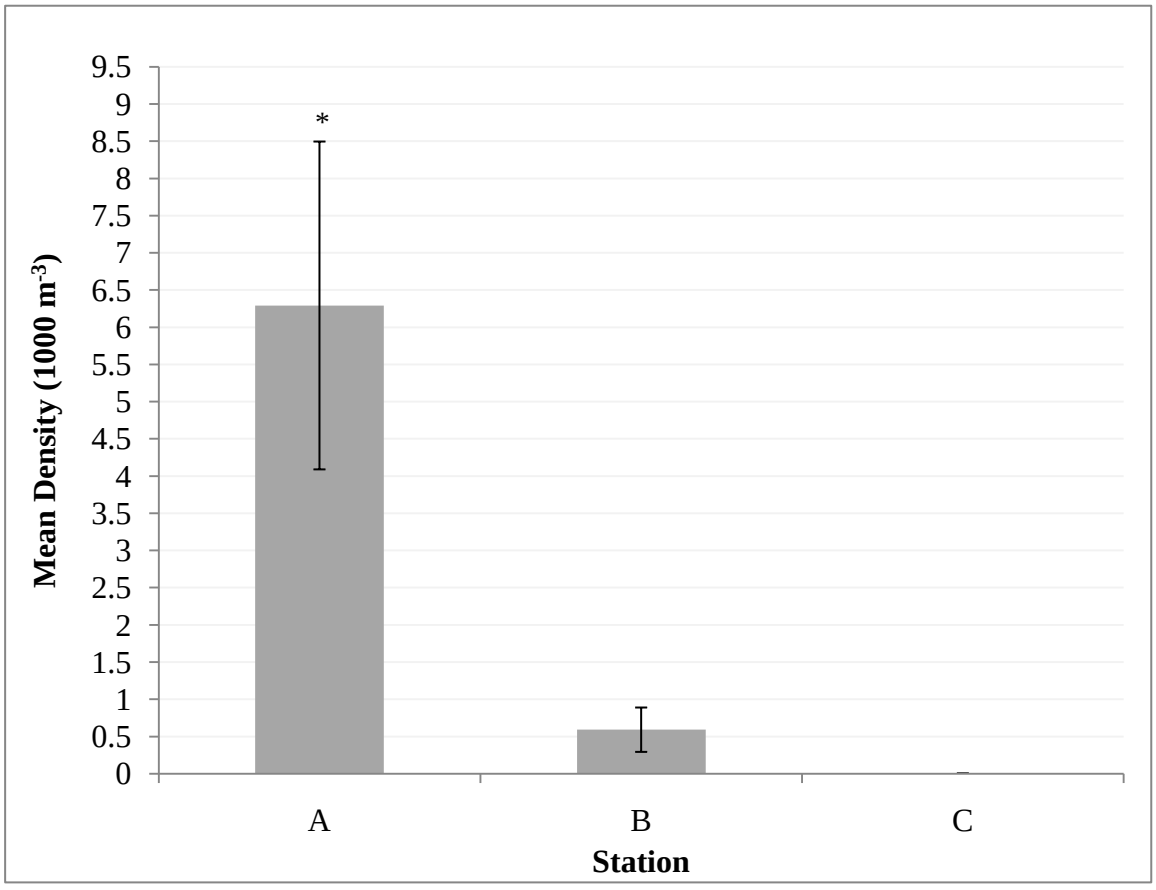


Figure 6: May sampling event mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops ($p<0.05$: Mann-Whitney *U*). Asterisk denotes a statistical difference.

Pairwise comparisons per monthly sampling event were analyzed for each station. Station A, (inshore), was found to be significant between the May sampling event and those from the months of February (p=0.021, Mann-Whitney *U*), March (p=0.009, Mann-Whitney *U*), September (p=0.009, Mann-Whitney *U*), and November (p=0.009, Mann-Whitney *U*) (Figure 7). Only July showed no significant difference when compared to May and no other monthly comparisons per station showed a significant density difference.

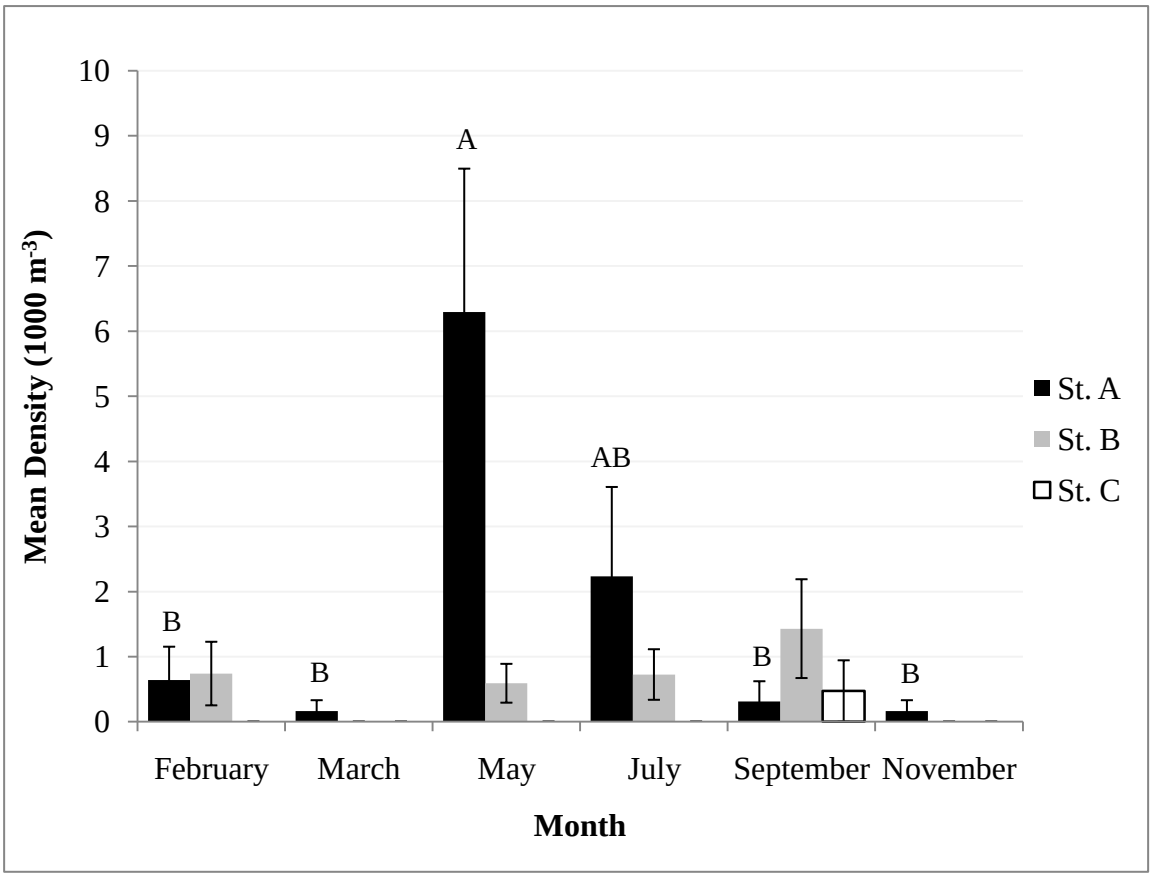


Figure 7: Monthly mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops per station per monthly sampling event. Means with different letters indicate a statistical difference ($p<0.05$: Mann-Whitney *U*).

Diel

Diel sampling was analyzed for stations A and B only as no nighttime sampling was conducted at station C. Mean densities of *C. sapidus* megalops across the entire year's sampling event showed no significant difference between day and night (p=0.52, Mann-Whitney *U*) (Figure 8).

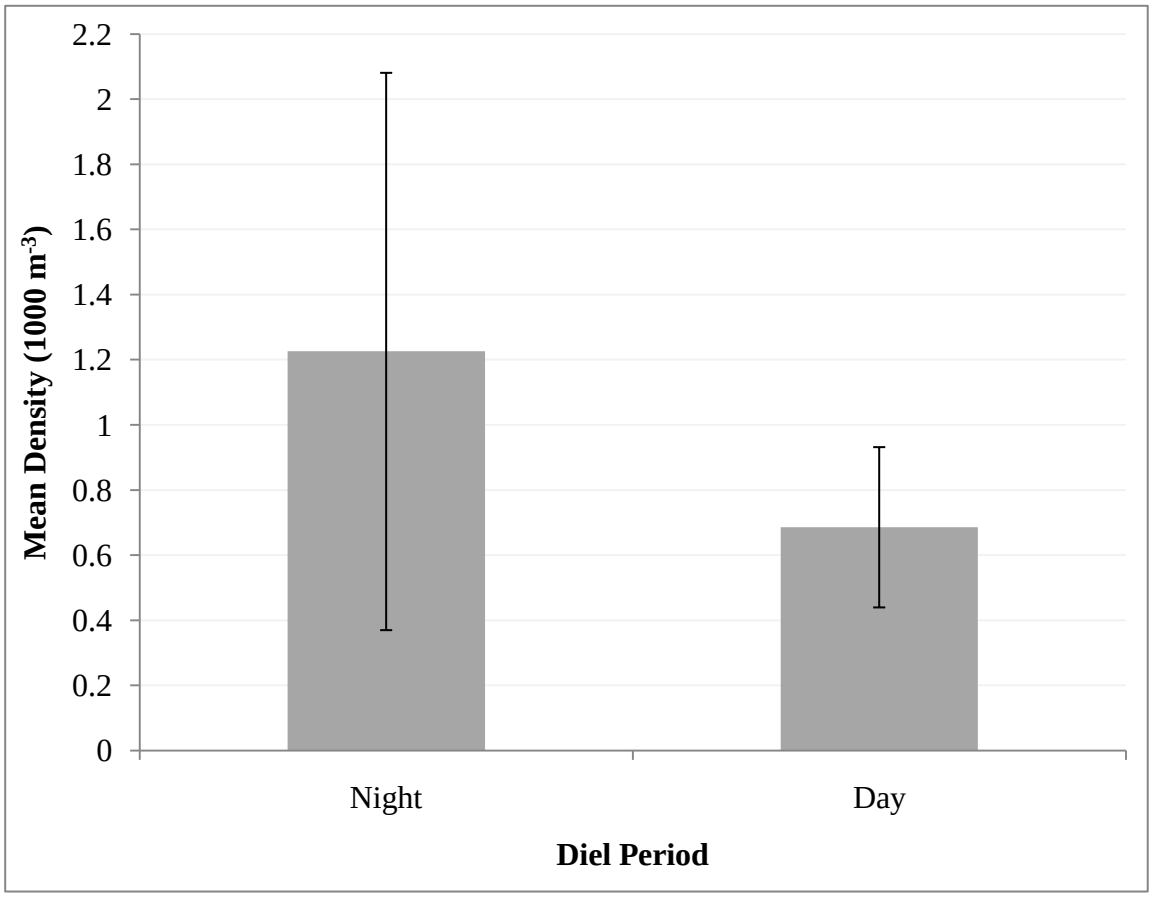


Figure 8: Mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops across the entire year's sampling per diel period shows no significant difference (p>0.05: Mann-Whitney *U*).

Further pairwise analysis showed no significant difference between diel period within each month (Feb.: p=1.0, March: p=0.38, May: p=0.11, July: p=0.22, Sept.: p=0.27, Nov.: 0.38, Mann-Whitney *U*) (Figure 9). A monthly pairwise analysis did reveal a significant difference in the nighttime samples (p=0.007, Kruskal-Wallis). A significant difference was seen between the May sampling event and the sampling events from the months of March (p=0.009, Mann-Whitney *U*), July (p=0.049, Mann-Whitney *U*), and September (p=0.018, Mann-Whitney *U*) (Figure 9). Daytime sampling showed no significant differences between monthly sampling (p=0.116, Kruskal-Wallis).

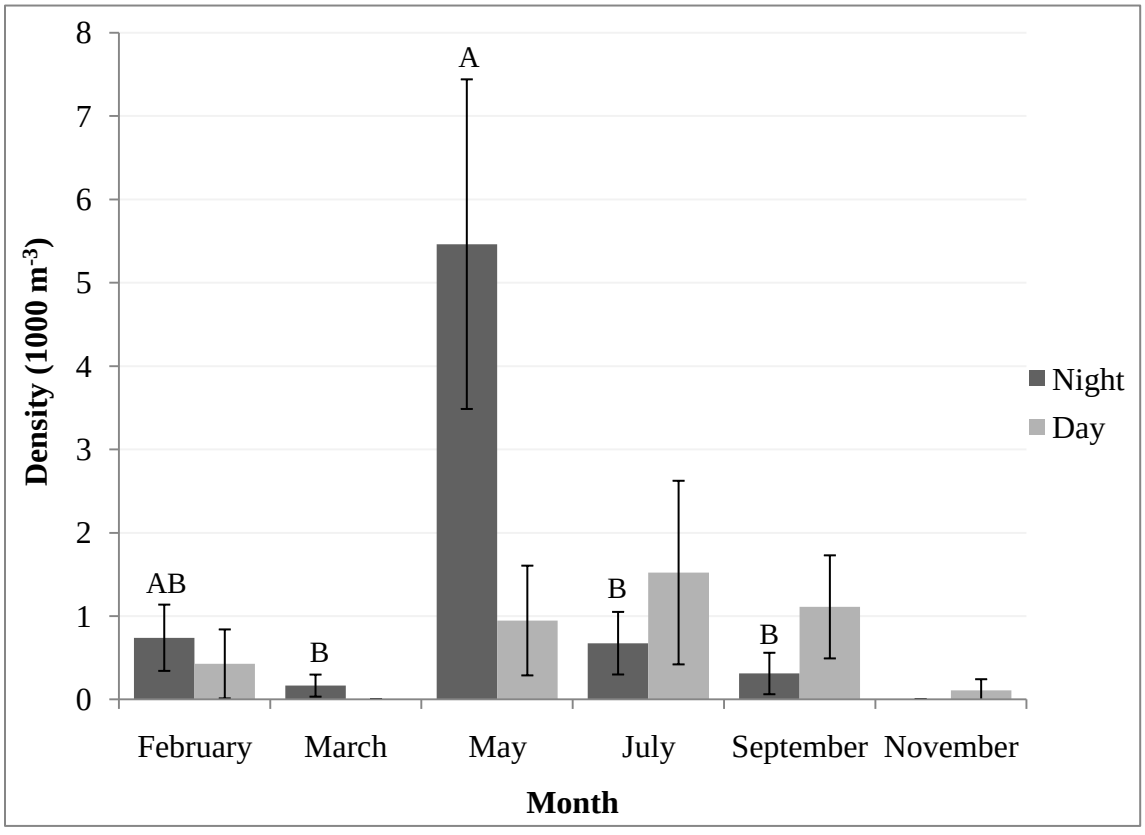


Figure 9: Mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops per monthly sampling event per diel period. Means with different letters indicate a statistical difference (p<0.05: Mann-Whitney *U*) among nighttime samples. No significant difference was seen in the daytime samples (p>0.05 Kruskal-Wallis)

Depth

Samples were categorized into two depth categories: 1. Upper 25 m, and 2. Entire water column. Samples from category 1 covered a depth range of 8 m to 36 m and those from category 2 sampled from 0 m to 299 m. Category 2, the entire water column, includes samples from the bongo net that targeted 0 m – 200 m and samples from the Tucker trawl, net B, that targeted the 25 m – 200 m range. Depth categories were compared over the entire year's sampling with no significant differences found (p=0.57, Mann-Whitney *U*) (Figure 10).

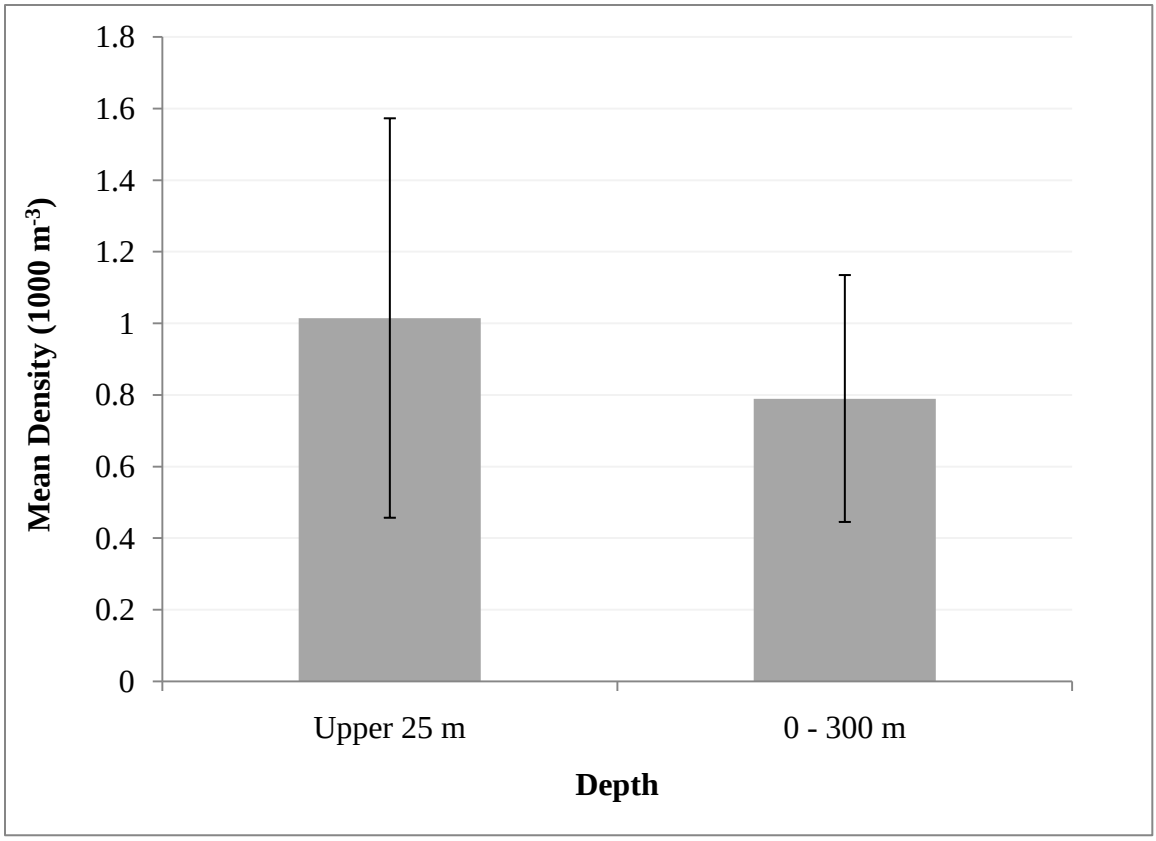


Figure 10: Mean Density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops per depth category over the entire month's sampling shows no significant difference (p>0.05, Mann-Whitney *U*).

Additionally, pairwise analysis within each month comparing depth categories revealed no significant differences (Feb.: p=0.83, March: p=0.32, May: p=0.90, July: p=0.53, Sept.: p=0.11, Nov.: p=0.32, Kruskal-Wallis). Finally, pairwise analysis of each depth category compared month to month showed no significant difference in category 1 (upper 25 m) sampling across months (p=0.63, Kruskal-Wallis) or in category 2 (entire water column) sampling across months (p= 0.108, Kruskal-Wallis) (Figure 11). However, further pairwise analysis showed a statistical difference in category 1 samples between the months of May and March (p=0.045, Mann-Whitney *U*) (Figure 11).

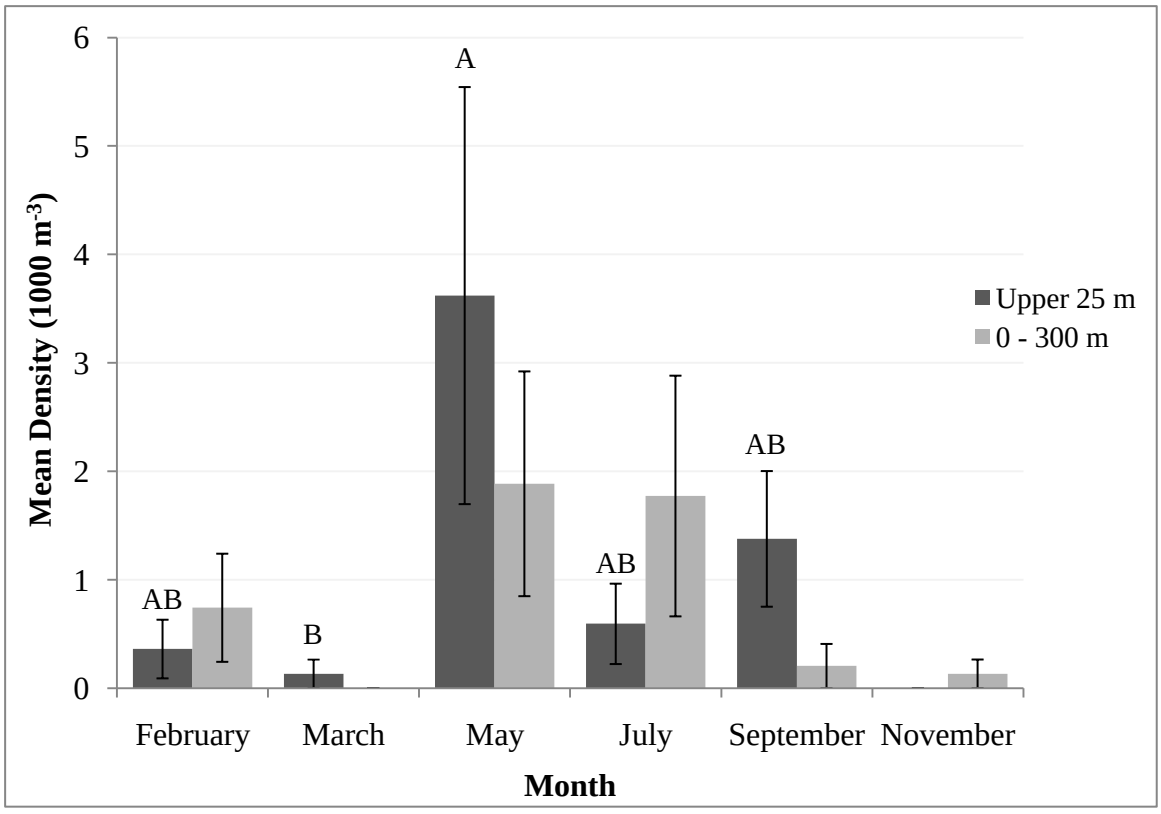


Figure 11: Mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops per monthly sampling event per depth category. Means with different letters indicate a statistical difference ($p<0.05$: Mann-Whitney *U*) within that depth category.

The upper 25 m depth samples were analyzed exclusively to gain a better perspective on densities from discrete water column sampling. Analysis between net mesh size densities from the upper 25 m water column revealed no significant difference ($p=0.17$, Kruskal-Wallis). Therefore, all analyses for the upper 25 m water column samples combined densities from both net types.

Mean densities of *C. sapidus* megalops from May remained the highest. A decrease in density was seen in the months of February, July, and November while an increase in density was seen during March, May, and September compared to the combined densities from all samples (Table 3).

Table 3: *C. sapidus* megalops mean density (1000 m^{-3}) (± 1 SEM) per monthly cruise comparing mean densities of the entire water column to the upper 25 m depth water column.

	Mean Density ± 1 SEM (1000 m^{-3})	
Month	**Mean Densities: Entire water column**	**Mean Densities: Upper 25 meters**
February	0.58 (±0.28)	**0.37 (±0.27)**
March	0.07(±0.07)	**0.13 (±0.13)**
May	2.75(±1.08)	**3.62 (±1.92)**
July	1.18(±0.59)	**0.59 (±0.37)**
September	0.79(±0.35)	**1.38 (±0.63)**
November	0.07(±0.07)	**0.00**

Monthly Cruise Sampling

As seen from the analysis comparing depth categories, a significant difference was not seen when all months were compared overall (p=0.063, Kruskal-Wallis). However, monthly pairwise comparisons showed a significant difference in *C. sapidus* megalops densities between the months of May and March (p=0.045, Mann-Whitney *U*) (Figure 12). There were no *C. sapidus* megalopa in the upper 25 meters samples in the month of November.

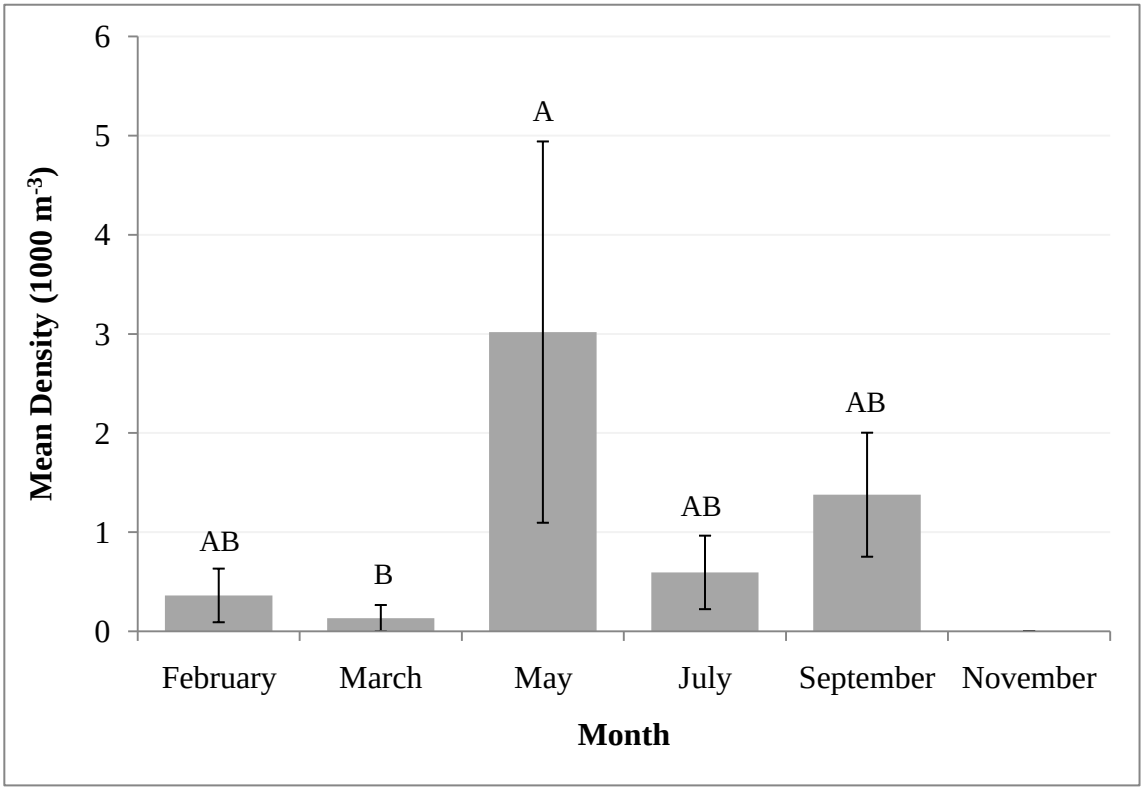


Figure 12: Mean density (1000 m^{-3}) (± 1 SEM) of *C. sapidus* megalops over the entire year's sampling exclusive to the 25 m depth samples. Means with different letters indicate a statistical difference (p<0.05: Mann-Whitney *U*).

Station

Mean densities of *C. sapidus* megalops were analyzed over the entire sampling period with no significant difference seen (p=0.245, (Kruskal-Wallis). Further pairwise analysis for each station over the entire year's sampling revealed no significant difference between stations (St. A to St. B: p=0.51, St. A to St. C: p=0.11, St. B to St. C: p=0.22, Mann-Whitney *U*.). In addition, each month was analyzed for significant differences in mean density between the stations with no significant difference revealed (Feb: p=0.73, March: p=0.44, May: p=0.22, July: p=0.44, Sept.: p=0.73, Nov.: N/A, Kruskal-Wallis).

Lastly, each station was analyzed for pairwise monthly significance with no significant difference seen between monthly sampling at each station (Figure 13). Although monthly densities at the inshore station (St. A) are much greater than was seen in other months, a significant difference was not seen during analysis. As a result of separating the upper 25 meters, sample size dropped to an $n = 4$ making the standard deviations high for each sample. A conclusion of significance, therefore, could not determined.

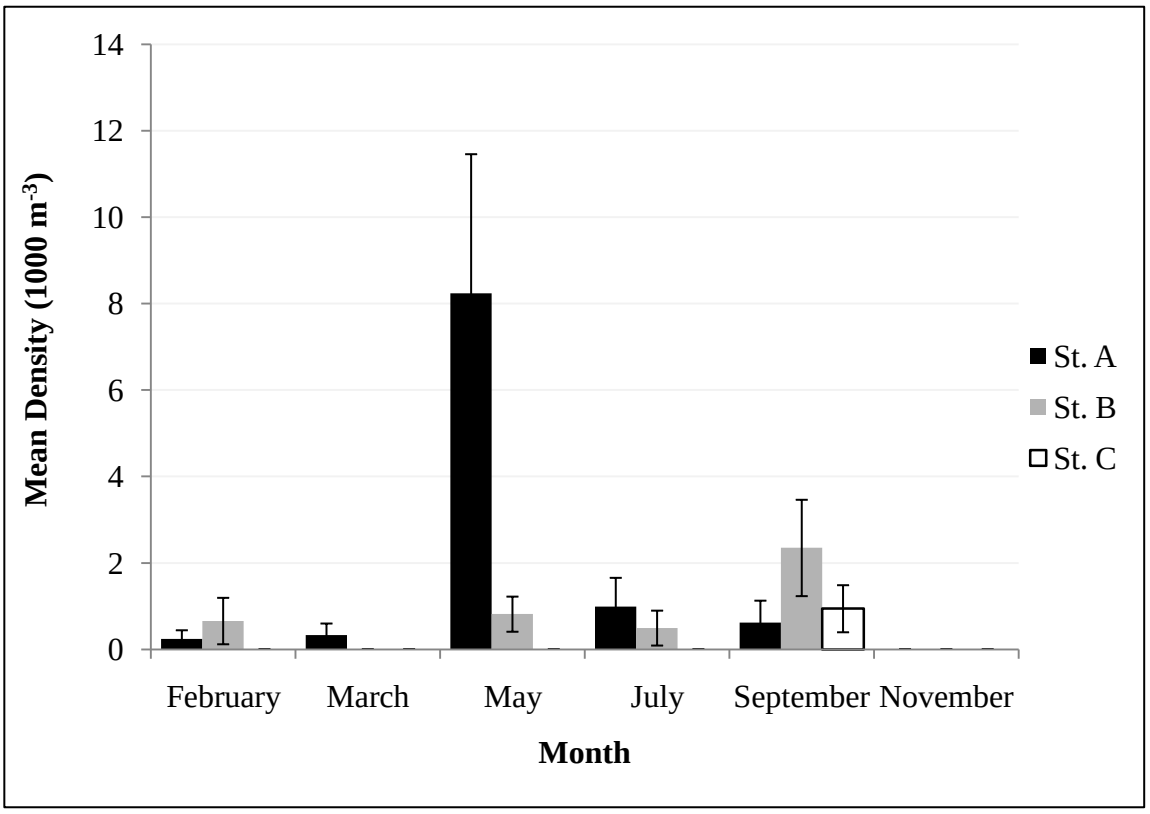


Figure 13: *C. sapidus* megalops densities per station per month for the upper 25 m water column sampling shows no significant difference ($p>0.05$, Mann-Whitney *U)*.

Diel

Diel patterns of *C. sapidus* megalops density were analyzed for the upper 25 m water column to see if a significant difference exists between daytime and nighttime densities. As station C (offshore) was not sampled at night, it was excluded from analysis. No significant difference was seen overall or within each month ($p=0.44$, Kruskal-Wallis) (Figure 14).

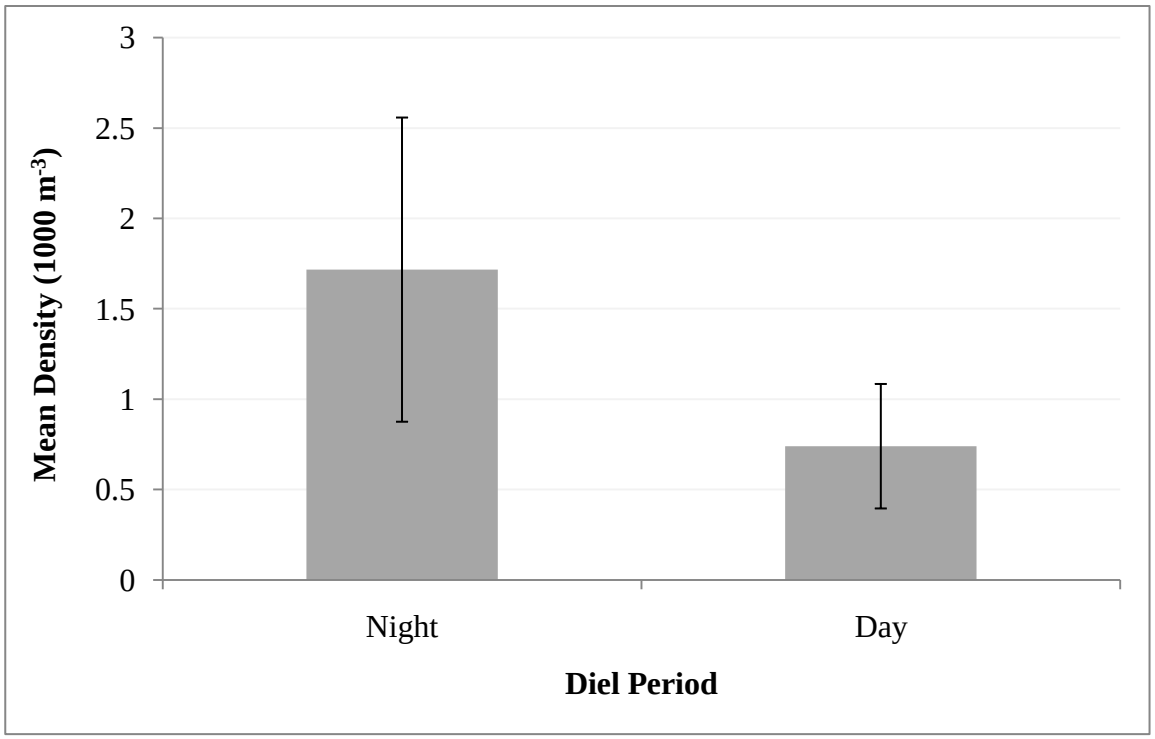


Figure 14: *C. sapidus* megalops mean density comparing diel period revealed no significant difference ($p>0.05$, Kruskal-Wallis)

4.4.2 Physical Analysis

CTD Data

Salinity and temperature data were collected during the monthly sampling in February, July, September and November only. No data was collected during the March, April, and May cruises. Across the entire sampling season, average at-depth salinities from the upper 25 m depth category ranged from 36.05 – 36.35 ‰ and ranged from 35.18 – 36.05 ‰ from the 0 – 200 m depth category (Table 4). Average at-depth temperatures from the upper 25 m depth category ranged from 25.22 – 30.06 ˚C and ranged from 8.06 – 19.16 ˚C from the 0 – 200 m depth category (Table 5).

Table 4: Average salinities per cruise per depth range.

	Average at-depth salinities (‰)	
Cruise	0-25 m	0-200 m
February	36.35	35.18
July	36.25	36.05
September	36.05	35.54
November	36.21	36.04

Table 5: Average temperatures per cruise per depth range.

	Average at-depth temperatures (˚C)	
Cruise	0-25 m	0-200 m
February	25.22	8.06
July	29.05	17.86
September	30.06	12.48
November	26.60	19.16

Analysis was done to look for any correlation between mean density of *C. sapidus* megalops and temperature or salinity changes. Mean density from the upper 25 m samples as well as from the entire water column were correlated to salinity and temperature changes. All samples with zero counts were removed before salinity and temperature correlations were calculated. All correlations were weak ($r^2 < 0.2$) and no significance was determined from any correlation (Upper 25 m: Sal.-Density p=0.356, Temp.-Density p=0.765, Entire water column: Sal.-Density p=0.867, Temp.-Density p=0.32; Spearman Rank Order) (Figures 15-18).

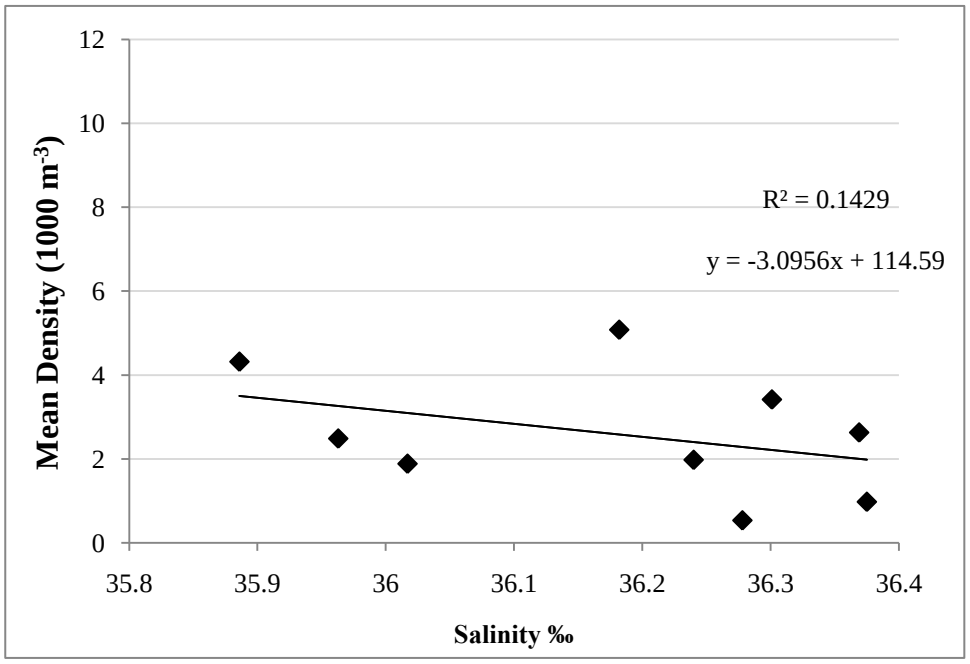


Figure 15: Salinity-Mean Density (1000 m^{-3}) correlation of the upper 25 m depth samples.

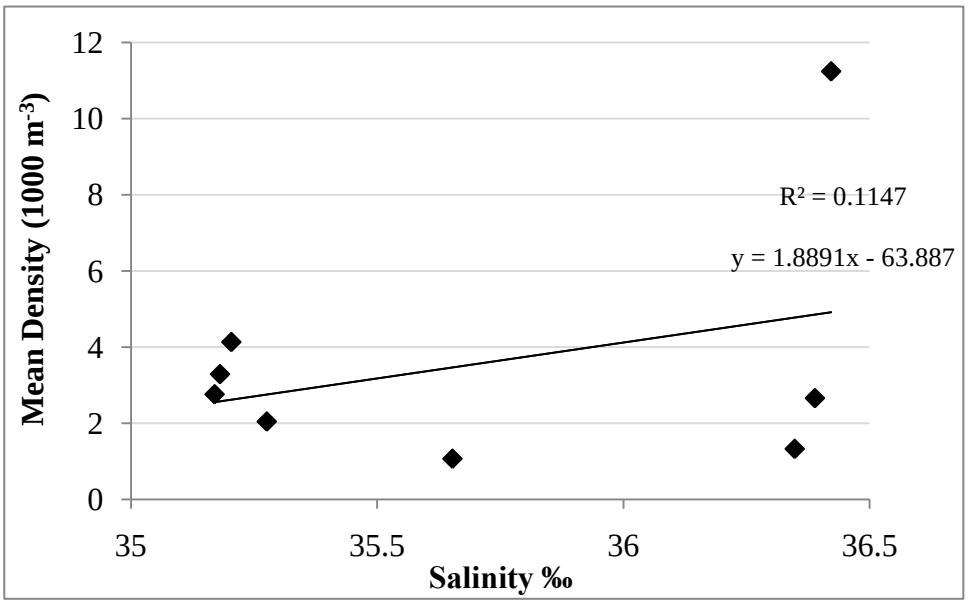


Figure 16: Salinity-Mean Density (1000 m^{-3}) correlation of the 0-200 m depth samples.

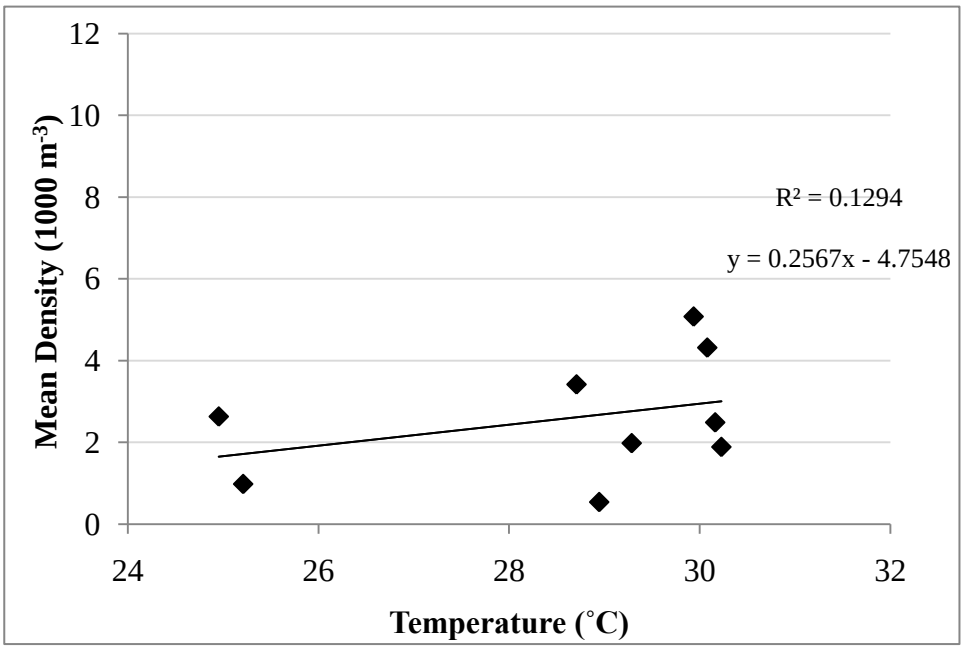


Figure 17: Temperature-Mean Density (1000 m^{-3}) correlation of the 0-25 m depth samples.

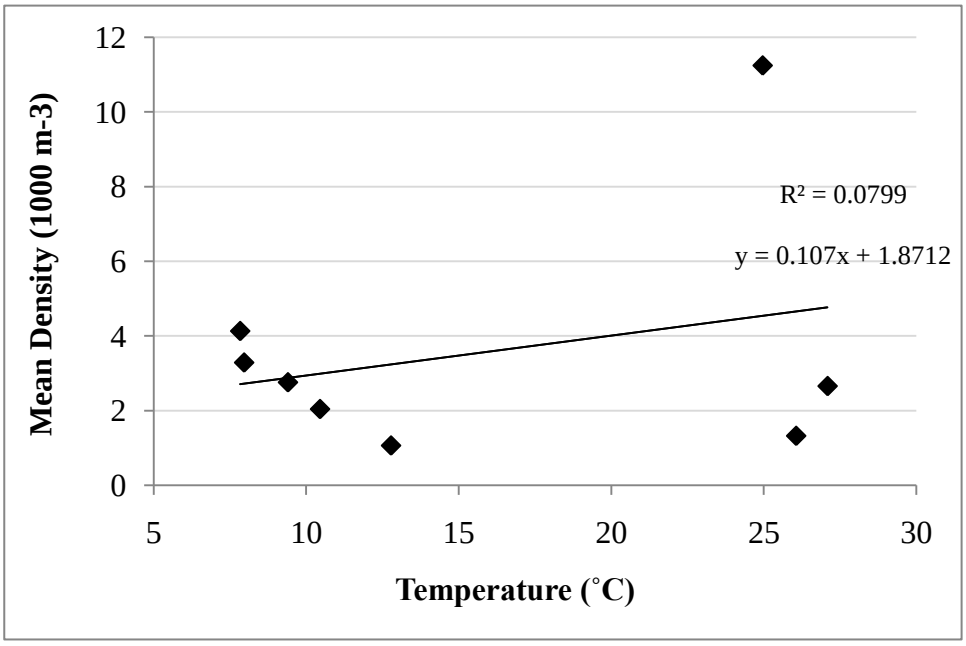


Figure 18: Temperature-Mean Density (1000 m^{-3}) correlation of the 0-200 m depth samples.

ADCP Data

Acoustic Doppler Current Profiler (ADCP) data were used to determine velocity (mm/s) of the Florida Current as well as direction of the current at each station during each monthly cruise. Velocity was used to determine where the western edge of the front lied at each station. Across all monthly cruises, the upper 25 m water column consistently flowed in a north/northeast direction. However, varying current velocities were seen throughout the rest of the water column as well as varying direction of the flow at all depths throughout the sampling period.

In February, the entire sampling area flowed in a north/northeasterly direction and velocity data revealed that Station A was outside the western edge of the current, Station B was on the western edge of the front and Station C was in the front (Figure 19). In March, some mixing of the water column was seen in bottom waters at station B and station A was situated on the western edge of the front (Figure 20). In April, there was a southerly counter current at station A from 50 m to 150 m. Both stations A and B in April were located out of the current while station C was at the western edge of the front (Figure 21). In May, a southerly counter current was seen at bottom depths at station A. All stations in May were in the Florida Current (Figure 22). July also showed all stations to be in a current and the flow had a north/northeasterly direction (Figure 23). In September, bottom depths showed a southerly counter current at station A and mixing at bottom depths at stations A and B. Stations A and B were out of the current in September (Figure 24). In November, the direction of the current was north/northeast at all stations and all stations were in the current (Figure 25).

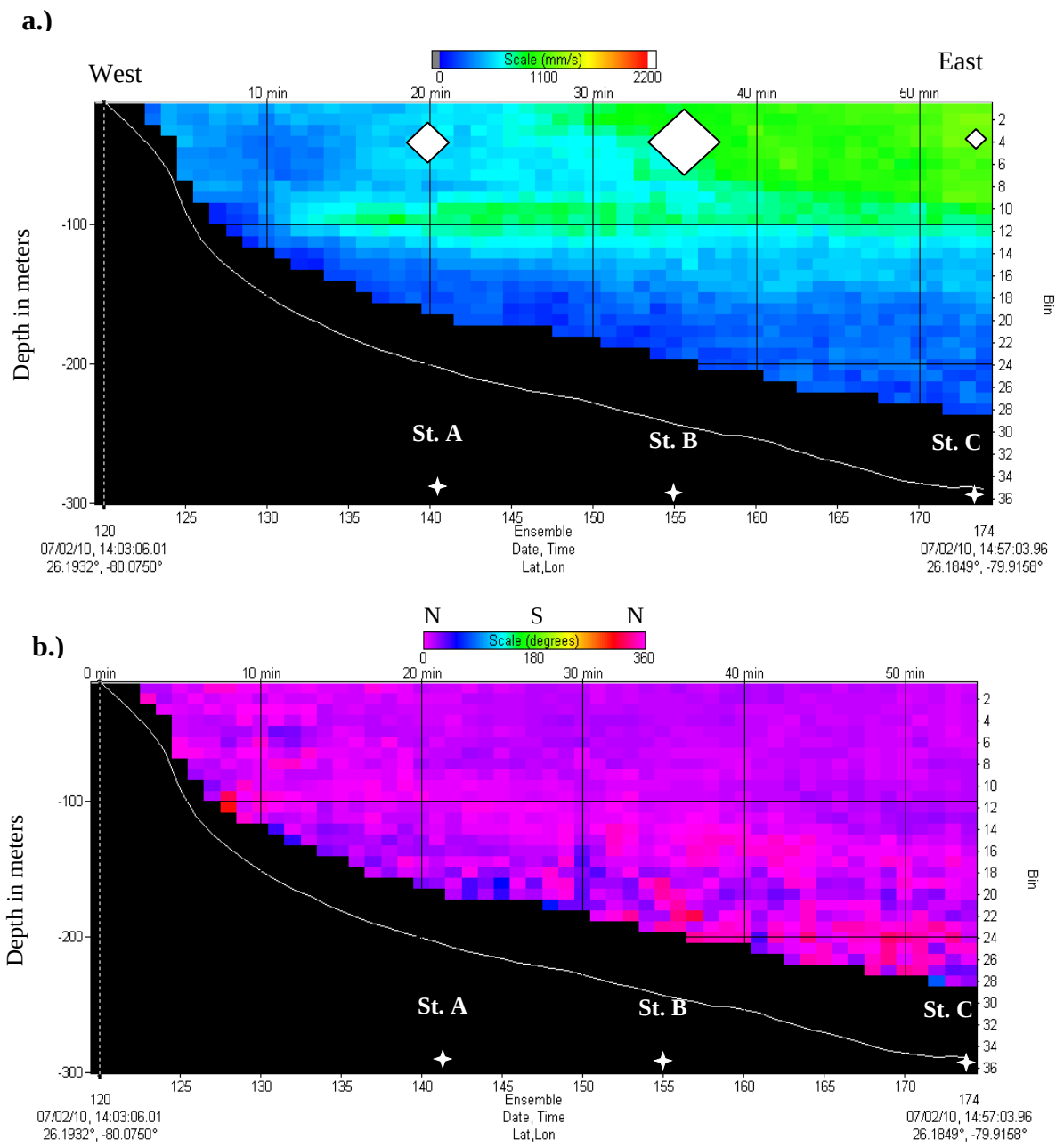


Figure 19: February ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).

◇ 0.0 - 0.07 ◇ 0.07 - 0.7 ◇ 0.7 - 7.0

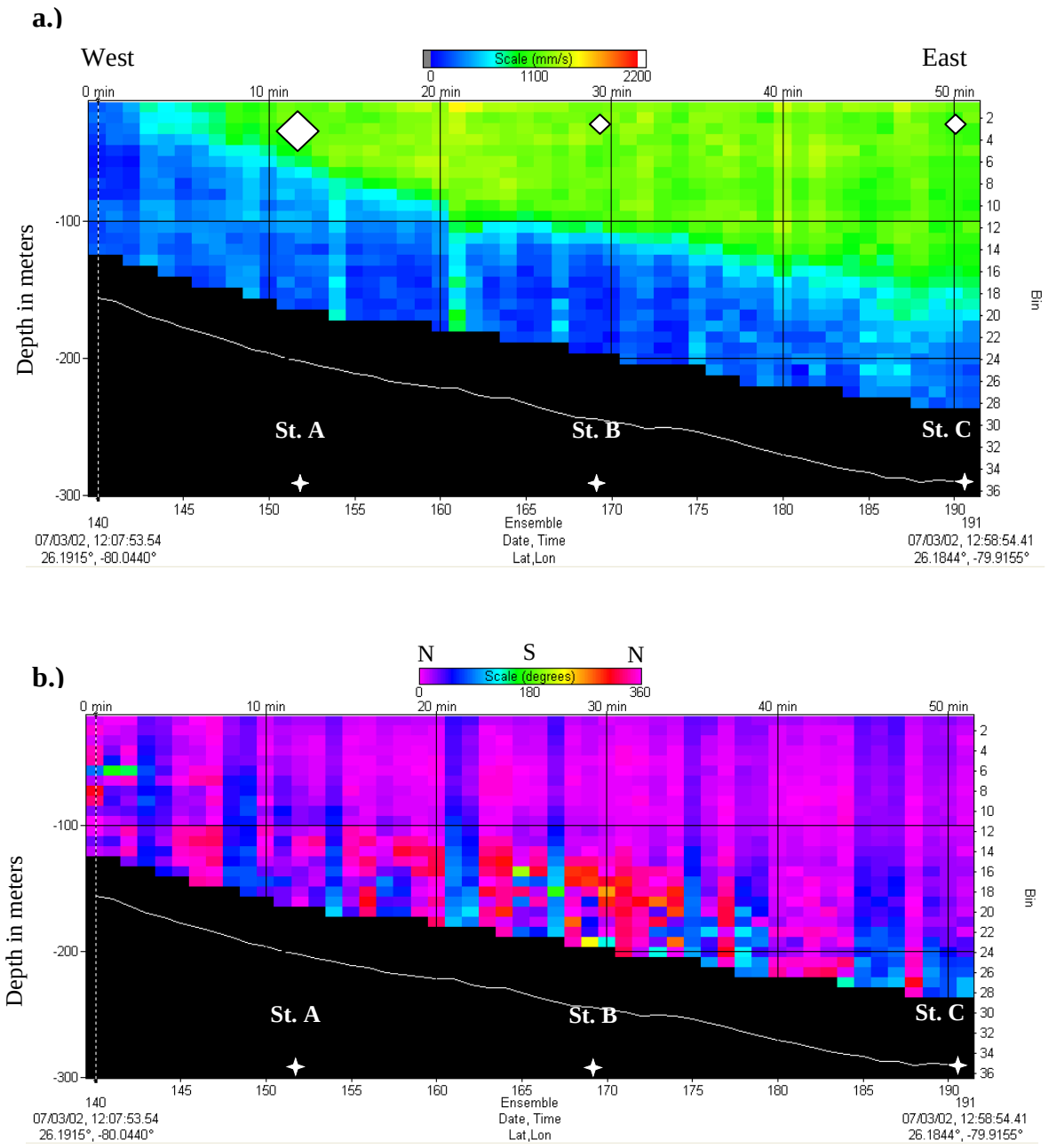
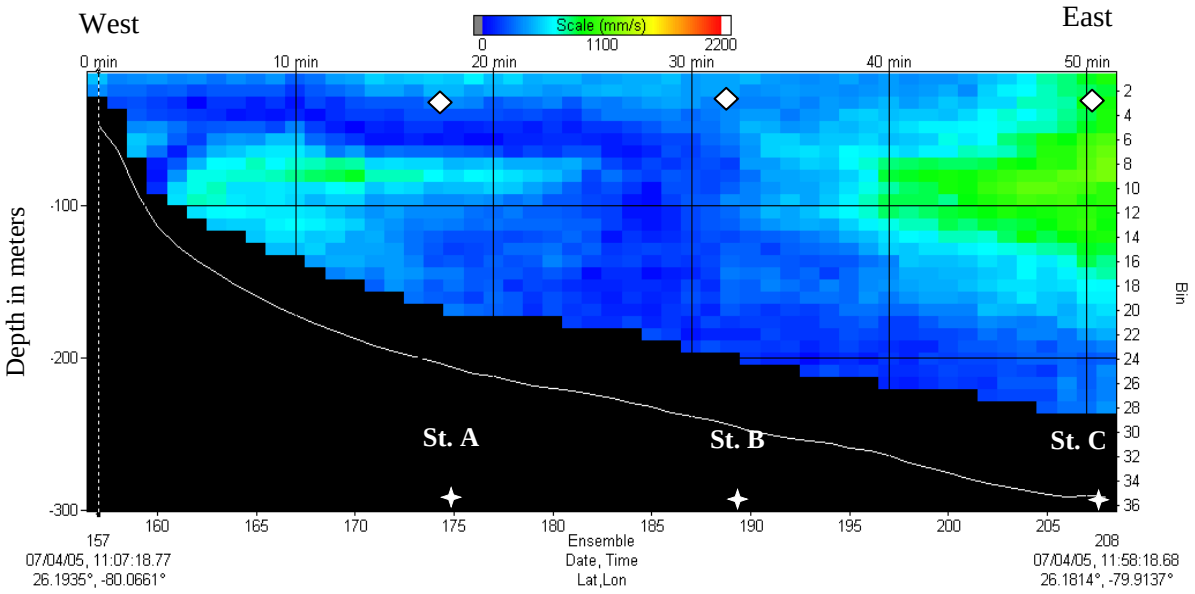


Figure 20: March ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).

◇ 0.0 - 0.07 ◇ 0.07 - 0.7 ◇ 0.7 - 7.0

a.)



b.)

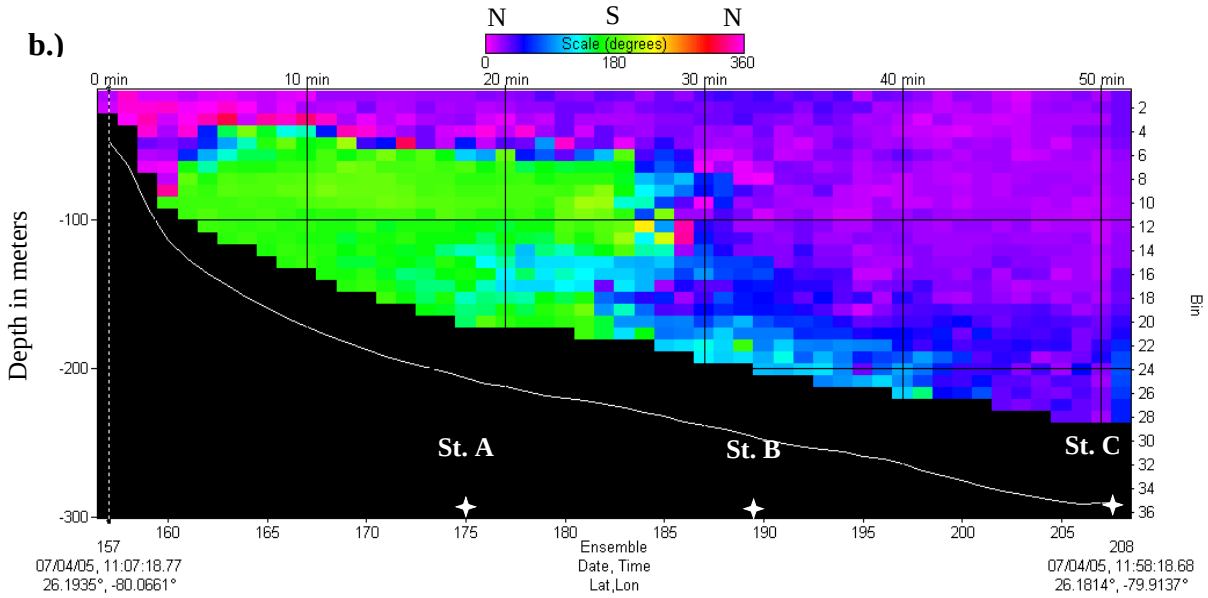
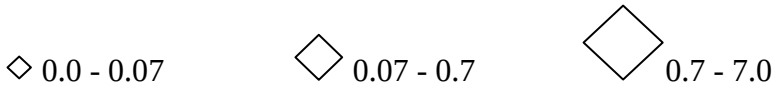


Figure 21: April ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).



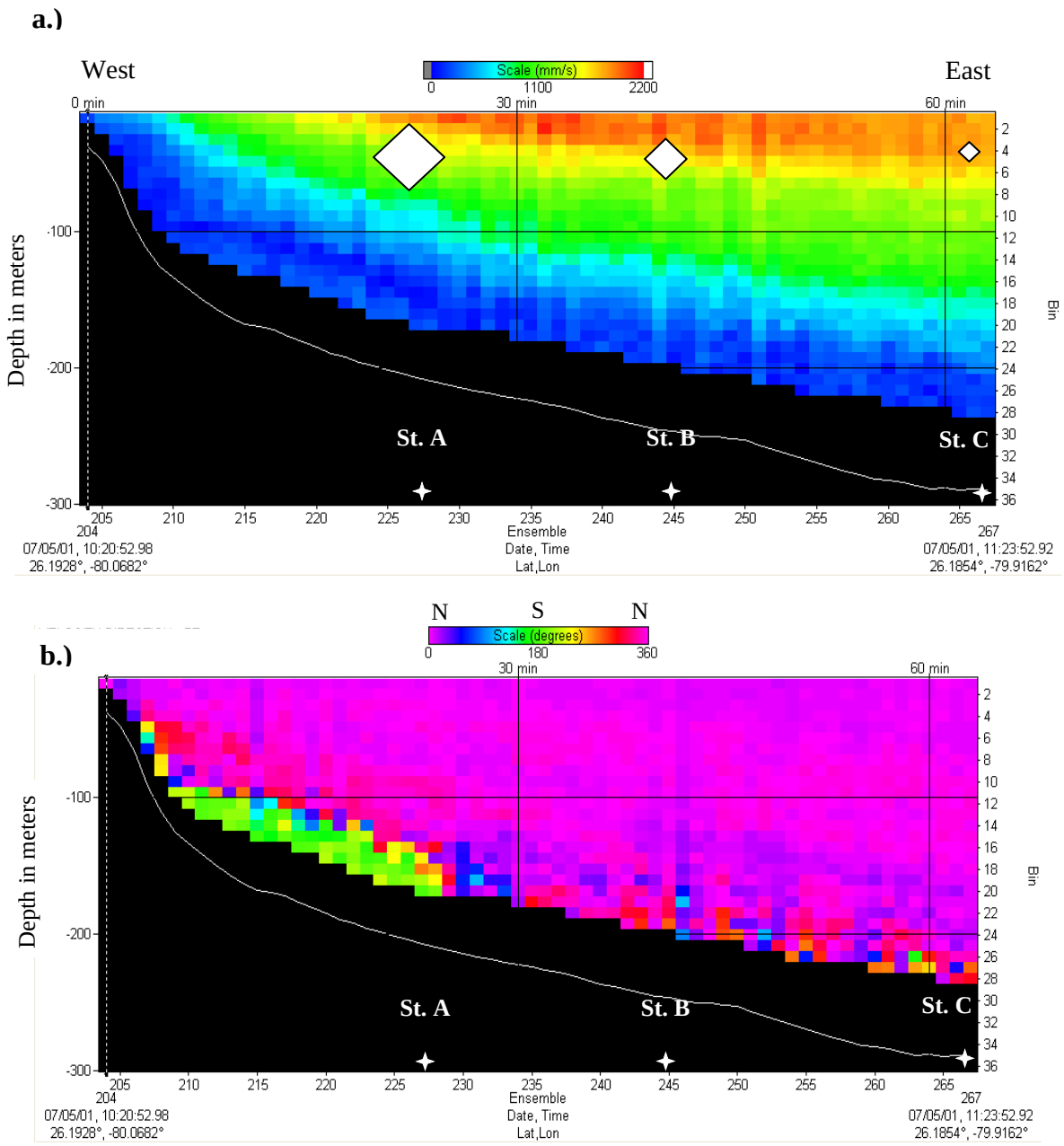
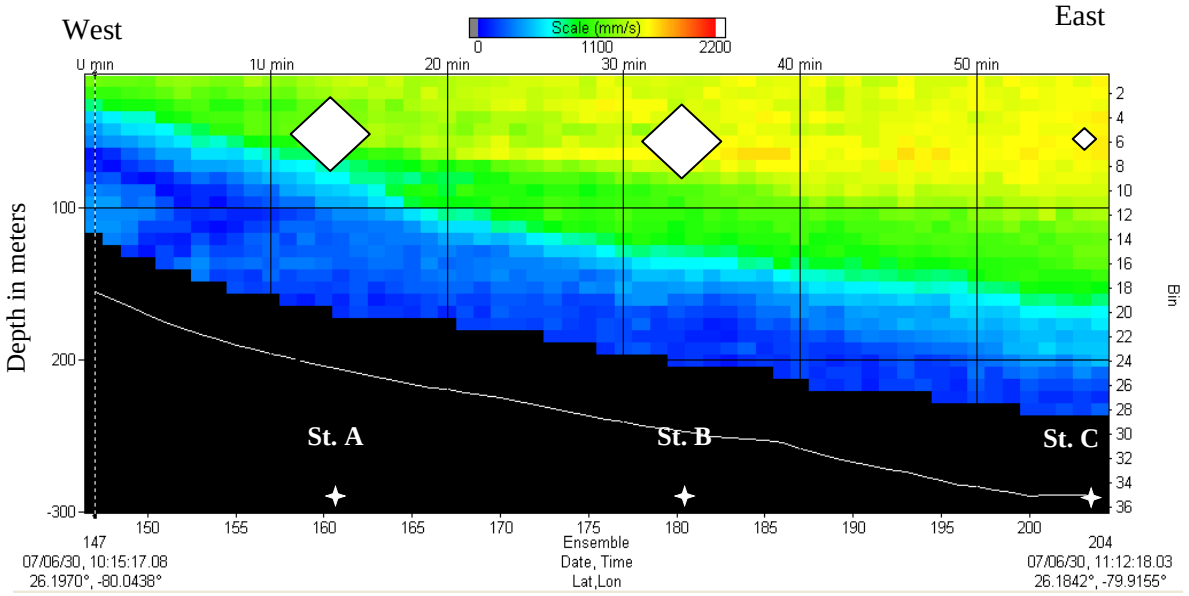


Figure 22: May ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).

◇ 0.0 - 0.07 ◇ 0.07 - 0.7 ◇ 0.7 - 7.0

a.)



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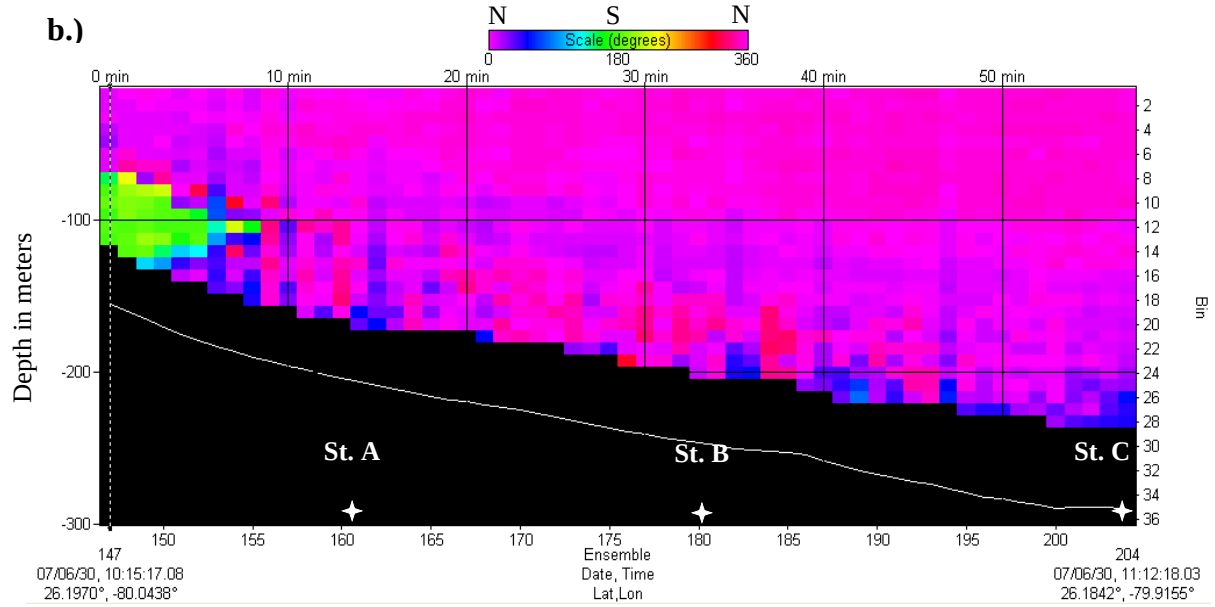
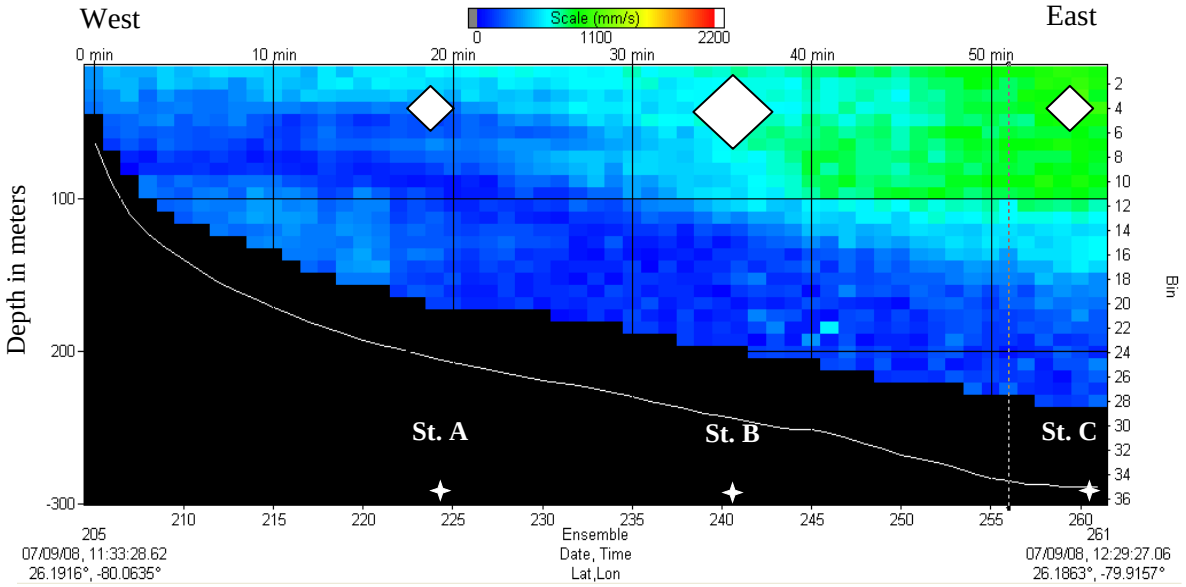


Figure 23: July ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).

◇ 0.0 - 0.07 ◇ 0.07 - 0.7 ◇ 0.7 - 7.0

a.)



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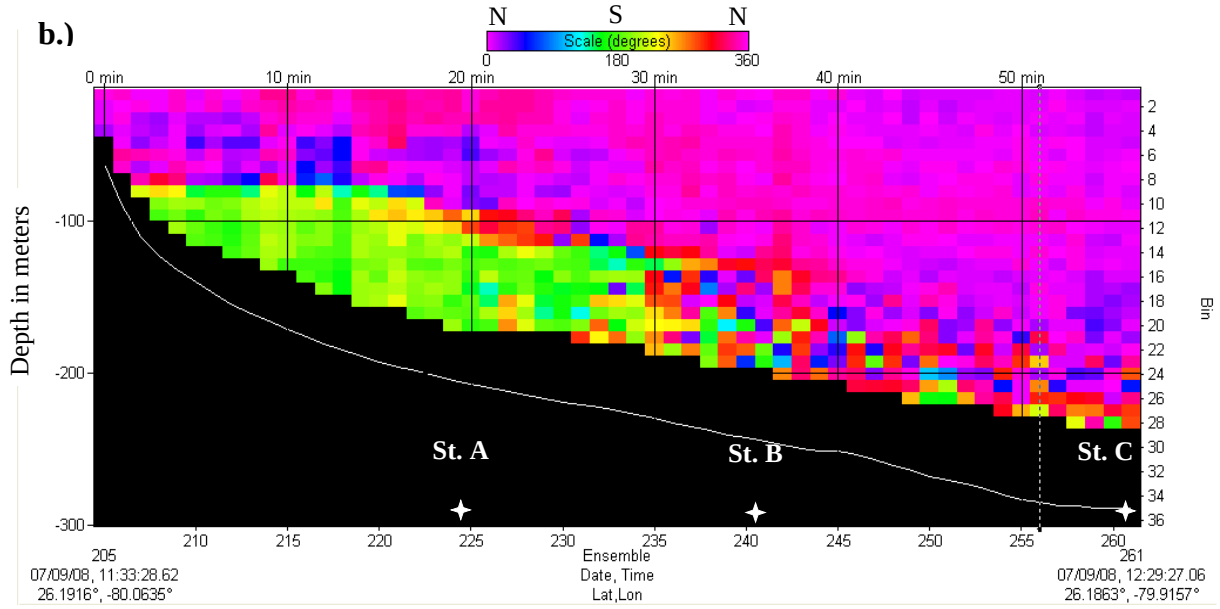
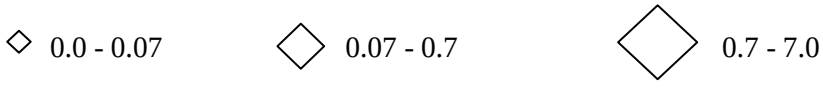
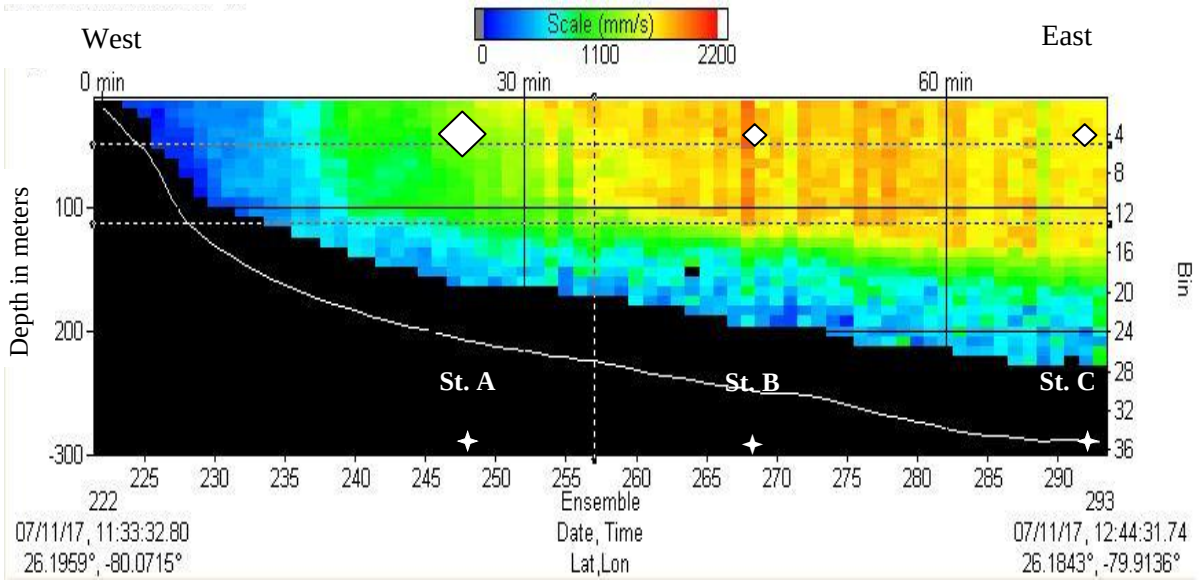


Figure 24: September ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalops per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).



a.)



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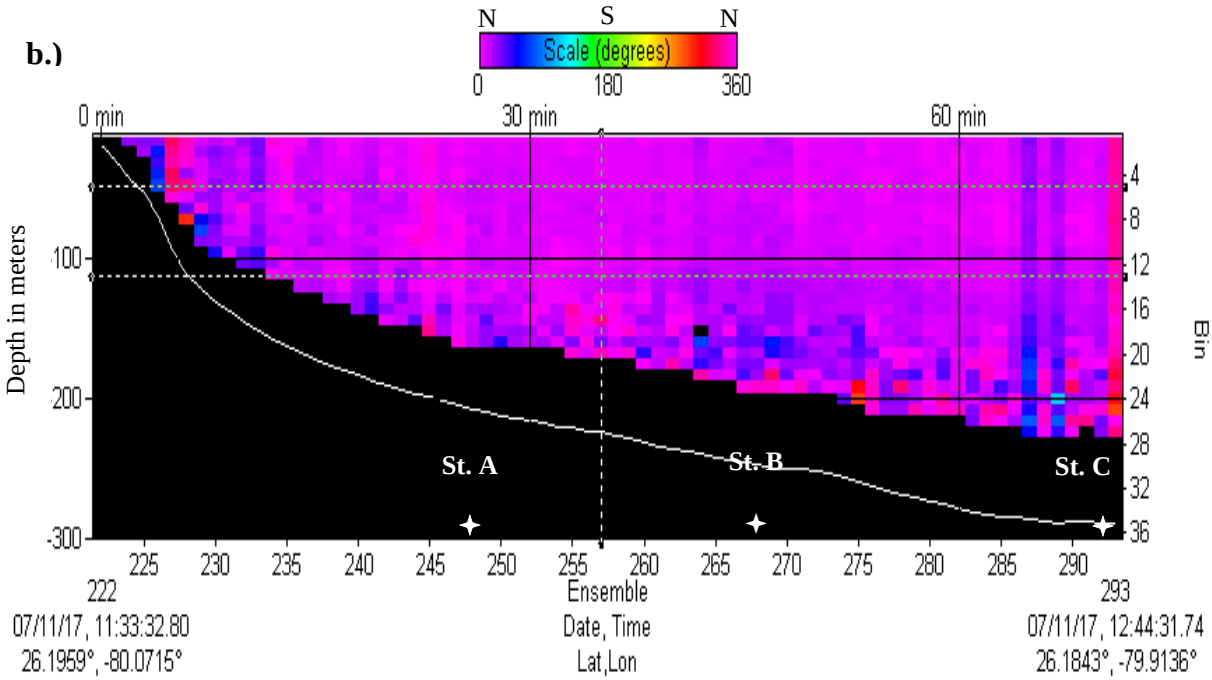

Figure 25: November ADCP Data showing Florida Current velocity (a) and direction (b). Densities (1000 m^{-3}) of *C. sapidus* megalpos per station shown in (a). St. A = inshore, St. B=middle, St. C = offshore. Adapted from USCG (2008).

◇0.0 - 0.07 ◇ 0.07 - 0.7 ◇ 0.7 - 7.0

4.5 Discussion

4.5.1 Larval Densities and Distributions

Results from this study show that densities of *Callinectes sapidus* larvae were much lower than expected. As a result, it is difficult to draw any conclusions about their abundance and distribution patterns in the Florida Current. Previous studies have reported densities of *C. sapidus* zoea of up to 400,000 10 m^{-3} (Mc Conaugha et al. 1983) and 68,000 10 m^{-3} (Provenzano et al. 1983) from the Chesapeake Bay, and as high as 100 m^{-3} from the St. John's River in Florida (Tagatz 1968). However, while densities from the current study compared to previous research were low, a pattern was seen across all sampling months. The megalopa stage was observed from every month's collection except April with a peak in May and pulses in July and September. This pattern confirms a year-round spawning of *C. sapidus* in southeast Florida with peak spawning in the spring and another in late summer. In the only other larval study on blue crab along the southeast coast of Florida, Tagatz (1968) found occurrences of the zoeal stage blue crab from April to October at the mouth of the St. John's River with a peak mating period in March and again in July. Given the known 30-40 day development time of *C. sapidus* larvae, this observed spawning correlates to the May peak in megalops as well as the pulses in July and September seen in the samples from this study.

Results also showed that the inshore and middle stations (stations A and B) had higher densities of megalops compared to the offshore station (station C) and that station A had the highest mean density across all sampling months. The highest densities per monthly cruise were most often seen at station A where three of the six cruises had the highest densities compared to those from station B.

No consistent pattern was seen to correlate density at a particular station relative to the position of the western edge of the Florida Current (FC). For example, the highest densities of megalops from station A occurred from the cruises in May (6.29 1000 m^{-3}) and July (2.23 1000 m^{-3}) and ADCP data from both months showed this station to be encompassed in the flow of the FC. In contrast, during the March and November sampling, the two months with the lowest densities of megalops at station A (0.74 1000 m^{-3} at each), ADCP data also showed this station within the front of the FC. Additionally, station B during the September cruise had the third highest density of megalops (1.43 1000 m^{-3}) during that month's sampling period and was positioned to the west of the edge of the front and out of the flow of the current. While it is clear from this study that densities from station A were significantly higher compared to station C, it is difficult to conclude from this data whether larval densities are affected by the position of the Florida Current.

The most unexpected result from this study was the absence of *C. sapidus* zoea from all monthly cruises. Though only additional studies will help explain this absence, several possible reasons can be offered. First, it is possible that salinity and temperature ranges from the sampling sites recorded by the CTD may not have been optimal. Compared to other studies, laboratory rearing of *Callinectes* spp. indicates that optimal salinities for growth are lower compared to the recorded ranges from this study as well as seen in one other field survey (Table 6). It is possible that larvae adapt to their environment and that the higher salinities seen during this study may be allowable ranges for larvae utilizing the FC. However, the extreme low densities of megalops observed from this study and the absence of zoea at all stages could indicate that the high salinity

range in the Florida Current does not provide a suitable habitat for these larvae and that higher salinities are a factor preventing *C. sapidus* from using the FC as a long-distance dispersal mechanism.

Table 6: Optimal salinity and temperature ranges for *C. sapidus* larvae from laboratory experiments and in situ data compared to the current study.

Study	**Date**	**Optimal Salinity (‰)**	**Optimal Temperature (˚C)**	**Lab/In Situ**
Costlow & Bookhout	1959	20-31		Lab
Nichols & Keney	1963	33.4-36 (recorded range)	27-29 (determined from highest abundance)	In situ
Sandoz & Rogers	1944	21-29	20-29	Lab
Smyth	1979	20-32	19-25	Lab
		Salinity (‰) Range	**Temperature (˚C) Range**	
Current Study (Recorded CTD Data)	2007	35.18-36.35	8.06-30.06	In situ

Absence of zoea from this study may also be due to a physical barrier which may exist that prevents larval transport to the FC. Processes of the FC, such as eddies, upwellings, and an associated counter current (Peters et al. 2002; Soloviev 2003) may act to keep early stage larvae nearshore. In their study from the southeast coast of the U. S., Nichols & Keney (1963) recorded higher numbers of first and second stage zoea close to shore while higher numbers of later stage larvae were found farther offshore. In comparing their observations to this study's current data, it can be speculated that zoea

may not be transported offshore until they have reached later stages and, thus, would not be seen in the samples until later in their development.

Additionally, it is possible that the sampling design of this study may not have targeted the area of the water column the species occupies during early stages. Several studies have observed high densities of early stage zoea in the neuston layer indicating optimal placement for transport out of estuaries and development over the shelf (Smyth 1979; Sulkin 1981; Provenzano et al. 1983). Sampling collection during this study did not target the neuston or the surface layers (1- 3 m) for any length of time. Both bongo and Tucker trawl nets merely passed through these surface layers on the way up from targeted sampling depths. Future research that targets the neuston layer as well as nearshore waters will provide a better understanding of zoeal distribution.

Finally, identifying portunid zoea, particularly stage 1 larvae, and discerning the congener species, *C. sapidus* and *C. similis*, proved to be quite challenging. Although every measure was taken to overcome this obstacle, it is possible that early stage zoea could not be identified and that this was a contributing factor to the low numbers of *Callinectes* zoea seen from the samples.

Another unexpected result from this study was the absence of *C. sapidus* larvae from the April samples. Given known spawning and development times, high densities of all stages of blue crab larvae from this month's cruise would have been expected. As no salinity or temperature data was recorded from this month, it is difficult to say whether this could have been a factor. However, ADCP data showed this month had markedly different processes than from all other sampling months. The FC during most sampling cruises flowed in a N/NE direction and had a general velocity of 1000 – 2000 mm s^{-1}.

However, a notable difference in the flow and position of the current occurred in April (Figure 21). During this month, the western edge of the FC was situated farther east than from any other month. Stations A and B were both west of the western edge of the FC and the water column at these stations had a velocity of 0 – 500 mm s^{-1}. Additionally, a counter current was seen at station A from about 30 m to the bottom and had a slightly higher velocity than the surrounding current which was flowing in a mostly easterly direction. Though further research would be helpful in determining if major changes in water column direction and velocity would affect larval density, it is striking that this difference was seen in a month when no larvae were found from the samples.

Patchiness in the plankton could likely be a contributor to the overall low abundances of larvae seen during this study. Though the sampling methods employed were designed to capture an accurate view of the biological makeup of the water column, a multitude of events, such as spawning events, can affect the presence or absence of a target species from the samples (Omori and Hamner 1982). Though patchiness can be species specific, seasonal, and affected by several biological factors, there is generally a lower estimation of plankton during sampling compared to actual densities. Several studies and models have been analyzed in an effort to standardize sampling to ensure the most accurate measure of density (Wiebe 1971; Omori and Hamner 1982). Future sampling done at smaller time intervals, with larger nets and increased volume of water, may help provide a more accurate picture of the density and spatial distribution of *C. sapidus* larvae.

4.5.2 Local Recruitment or Long Distance Dispersal?

Current research on recruitment and dispersal of estuarine larvae focuses on their vertical distribution in the water column. It is commonly agreed that larvae rise and sink in the water column not just in response to diel cycles or for predator avoidance, but as a means of positioning themselves in the water column in order to catch onshore and offshore currents which transport them to higher salinity shelf waters or up-estuary to parent populations (Epifanio and Garvine 2001; Forward et al. 2003; López-Duarte and Tankersley 2007). While the cues that trigger this active migration in the water column are currently under research, it is known that zoea generally remain in the surface waters as a means of being carried away from estuaries by ebb tides while the megalopa outside the estuary sink into the water column to be carried shoreward by subsurface flood tides. The low densities and integrated water column sampling from this study make it difficult to conclude whether vertical larval distribution in the FC plays a role in recruitment of *C. sapidus* larvae to estuaries. Discrete sampling at multiple depths will provide valuable information on whether this activity is an important behavior used by *C. sapidus* larvae in south Florida waters.

The fate of plankton in current systems has been studied for decades and has important implications for estuarine species whose populations depend upon their larvae returning to the estuaries. Using a simulation model for larval fish dispersal, Porch (1998) determined that larvae with a planktonic phase lasting up to 30 days can survive dispersal in the currents and repopulate parent populations in areas with physical processes that retain them. Otherwise, the model showed that the FC would act to flush these larvae from southeast Florida waters. Given the location of estuarine ecosystems in south Florida and the physical processes of nearshore and offshore waters along Florida's

Atlantic Coast, combined with the results from this study, it is speculated that there are three possible paths of dispersal for *C. sapidus*: 1) That they are dispersed northward within the FC from spawning areas in the Florida Keys and Biscayne Bay and either lost from local parent populations as they are transported north without finding their way back into an estuary or, alternatively, they are caught up in eddies or shoreward flowing tides and repopulate northern Florida estuaries like the St. John's River, 2) They are entrained locally, never making it into the FC but, instead, exhibit self recruitment using active vertical migration and the ebb and flood tides to remain locally entrained, or 3) They are swept into the FC but are transported shoreward then southward in counter currents that transport them to Biscayne Bay or the Florida Keys (Figure 26). The low densities seen from the current study indicate that larvae most likely are not using the Florida Current for long-distance dispersal and it can be concluded that a dispersal pattern seen from the second scenario seems most likely for *C. sapidus* larvae in south Florida waters.

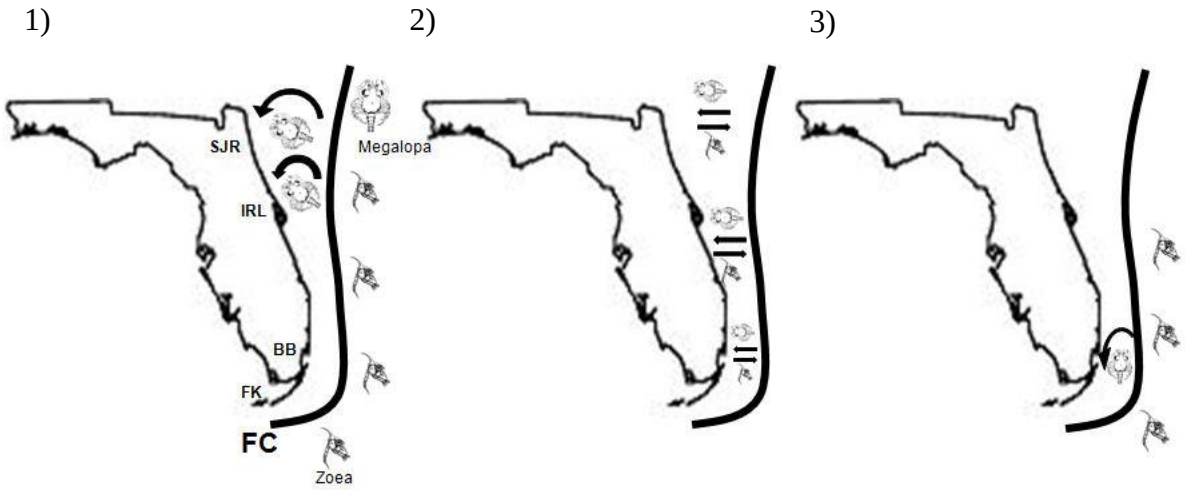

Figure 26: *C. sapidus* dispersal potential along the Florida Atlantic coast. Larvae are either lost to the Florida Current (FC) or entrained in eddies (1), exhibit local self-recruitment using active vertical movement in the water column allowing them to be transported out of and into estuaries on ebb and flood tides (2), or are transported in the FC and then dispersed south on counter currents (3).

Development time compared to the velocity of the Florida Current recorded during sampling provides further evidence that larvae are likely not using the current for long distance dispersal. The slowest speed recorded by ADCP during sampling was approximately 1100 mm s^{-1} and the highest speeds reached were 2000 mm s^{-1}. If travelling from the northern Florida Keys, larvae would have to travel approximately 88 miles. At a velocity of 2000 mm s-1 (5 mph), it would take 17 hours for larvae to reach the sampling site in this study. If travelling in the current at 1000 mm s^{-1} (2.2 mph), the time to reach the sampling area would take 40 hours. Given that it takes a minimum of 30 days to reach the megalopa stage, if the larvae had been travelling at an average speed of 1500 mm s^{-1} (3.4 mph), they would have had to travel 2400 miles to reach the sampling site. This scenario does not seem feasible and further supports the conclusion that long-distance dispersal is not the mechanism by which *C. sapidus* larvae are repopulating local parent populations. While further sampling is necessary to determine how local recruitment is happening, this seems the more likely scenario.

5.0 *Chaceon fenneri* (golden crab)

5.1 Introduction

The golden crab, *Chaceon fenneri*, represents a small and slowly developing fishery in Florida. However, few studies have been conducted on their life history and population dynamics in the Atlantic waters of the southeastern United States. The fishery for *C. fenneri* was developed off the east coast of Florida in 1985 (Erdman and Blake 1988b) but remains small and reports the fewest landings of the three commercially harvested species of crab in Florida waters. Despite minimal of landings, a fishery management plan (FMP) was established in 1996 (NMFS 2004). Effective management, however, can only be successful with detailed knowledge of this species' life history and population dynamics. Such parameters are especially important for this fishery as spawning occurs within the Florida Current creating a greater potential for long-distance dispersal and flushing from parent populations (Kelly et al. 1982). Only one study to date has been conducted in the Gulf of Mexico (GOM) waters, to identify *C. fenneri* larvae in the water column (Perry et al. 1991) while no larval studies have been conducted in east coast Florida waters.

5.1.1 Fishery

The Florida fishery for *C. fenneri* began on the west coast of Florida in 1984 but soon ended in late 1985 at the same time a fishery was developed off Ft. Lauderdale (Erdman and Blake 1988b). The southeast waters of Florida give this fishery an advantage due to the unique narrow continental shelf and deep waters close to shore which allows fishermen to deliver live crabs to market, keeping costs lower than those fishermen who remain at sea for long stretches (Erdman and Blake 1988b).

The golden crab fishery is managed by the South Atlantic Fishery Management Council (SAFMC) which established an FMP for this fishery in August of 1996 (SAFMC 2009). However, even before the management plan was implemented, the fishermen were following regulations of their own, throwing back all the females and those males with less than 130 mm carapace width (CW) (Erdman and Blake 1988b; SAFMC 2009). Today, females continue to be thrown back along with all crabs weighing under 1 ½ pounds (SAFMC 2009). The only allowable gear for the fishery are traps equipped with two main entrance doors secured with degradable wire and outfitted with two escape doors (SAFMC 2009). Fishermen look for catch rates of 20-30 pounds per trap but in high season catch rates can be upwards of 70 – 100 pounds per trap (SAFMC 2009).

The fishery is divided into three zones, the Northern, Middle, and Southern, along the southeast coast of the United States which includes the waters from the Virginia/North Carolina border south to the southernmost management area of the South Atlantic Fishery Management Council, south of the Florida Keys (NMFS 2004). Off of Fort Lauderdale, FL, the fishery lies within the Middle Zone which stretches from 28° N to 25°N latitude, from Malabar to Tavernier (Harper et al. 2000; NMFS 2004). Originally, 37 permits were issued to commercial fishermen for all zones but as of 1995, only 14 of those had reported landings, and, more recently, just five to six boats reported landings, most of them from the Middle Zone. Northern Zone fishermen reported landings in 2006 and 2007 only, despite them holding 27 of the 35 permits. For all zones combined, only 50% of the permit holders since 2001 have reported landings (NMFS 2004). Fishermen are not allowed to fish in zones for which they are not permitted (SAFMC 2009).

Landings for all three zones reached their highest in 1997 with over 1 million pounds reported. Yearly landings since have averaged 550,000 pounds (SAFMC 2009). The Middle Zone reported the majority of landings with a peak in 1997 of 662 thousand pounds declining to 352 thousand pounds by 2003 (NMFS 2004). The fishery, as of a 2000 report, is not considered overfished or currently experiencing overfishing (Harper et al. 2000; NMFS 2004). Despite this, current fishery regulations include: mandatory logbook form for each trip, restricted fishing zones, authorized gear types, and prohibited sale of females.

5.1.2 Life History

Golden crabs are a brachyuran crab in the family Geryonidae. They inhabit the upper continental slope of the waters of the Atlantic Ocean and parts of the Pacific Ocean. They are typically found at depths ranging from 250 m to 500 m, though they have been found as deep as 915 m in eastern Florida waters (Lockhart et al. 1990; Erdman et al. 1991; Stuck et al. 1992). Geryonids are large crabs with the males of *C. fenneri* reaching 139 mm carapace length (CL) and females reaching 114 mm CL (Manning and Holthuis 1984). Golden crabs, typical of all geryonids, display a distributional behavior where females separate themselves in depth from males which are typically found at deeper depths than females. This separation in depth is the result of females ascending the slope to depths shallower than 500 m to spawn, a behavior hypothesized as a developmental advantage allowing larvae to mature in warmer waters (Lindberg et al. 1990; Lockhart et al. 1990; Lindberg and Lockhart 1993).

Golden crabs are known to mate year round in the Gulf of Mexico with larval release occurring from the beginning of February to the end of March (Erdman and Blake

1988a; Lockhart et al. 1990; Perry et al. 1991). There is little knowledge of larval development in situ though rearing experiments indicate they remain in surface waters during at least the early stages of larval development (Hines 1990). From these laboratory experiments, larvae are known to develop through four zoeal and one megalopa stage which takes 33-40 days to complete (Stuck et al. 1992).

5.2 Materials and Methods

5.2.1 Species Identification

Samples were analyzed for the occurrence of Geryonid crabs which were identified to species level and staged using the larval description from Stuck et al. (1992). The overall morphology of the telson, abdomen and antenna, as well as overall size, was used as a key identifier to the genus level (Figure 27). For positive identification to the species level, measurements were made using the protocol of Stuck et al. (1992). Total length (TL), carapace length (CL), dorsal spine length (DSL), spine tip width (STW) and total spine length (TSL) are some of the most distinguishing morphological features of brachyuran crabs. Measurements of these were taken and compared to those from the larval descriptions of both *C. fenneri* and its congener, *C. quinquedens,* the deep sea red crab (Stuck et al. 1992). Analysis was conducted using an Olympus SZX7 stereomicroscope fitted with a 1.5X objective. Imaging and measuring of specimens was done using a 3.3 MPX camera attached to the microscope and transferred to a PC with Rincon Image Analysis Software. Stage determination relied exclusively on maxilliped exopod setation, where maxilliped 1 bears 4 plumose setae in Stage 1, 10 plumose setae in Stage 2, 13 – 14 plumose setae in Stage 3 and 17 – 18 plumose setae in Stage 4 (Figure 27) (Stuck et al. 1992).

Where measurements did not confirm a positive identification, the fifth somite of the abdomen was examined which, according to Stuck et al. (1992), is the most obvious distinguishing feature separating *C. fenneri* from *C. quinquedens*. In *C. quinquedens* there is the presence of a small dorsolateral spine on the 5th somite of the abdomen which has never been observed in *C. fenneri* (Figure 27) (Stuck et al. 1992).

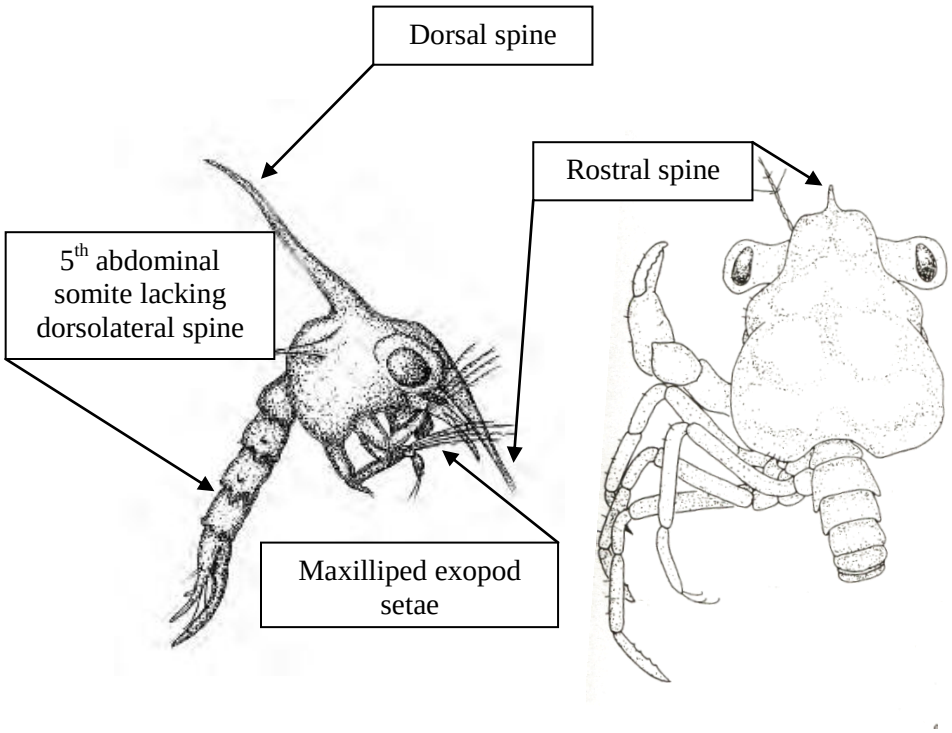

Figure 27: Key morphological features of *Chaceon fenneri* zoea and megalopa. Adapted from Stuck et al. (1992)

5.3 Results

C. fenneri did not occur in great enough abundance for statistical analysis of temporal and spatial patterns. A total of five larvae were identified; four Stage 1 zoea

and one Stage 2 zoea. No Stage 3, 4, or megalopa were identified from the samples. One specimen was found from station A, three from station B and one from station C. Of the four Stage 1 zoea, two were found from the bongo net and two from the Tucker trawl. The Stage 2 zoea was found from the bongo net. All specimens occurred from samples at the 0 – 25 m depth range (Table 7).

Table 7: *Chaceon fenneri* zoea identified from samples. Station A = inshore, station B = middle, and station C = offshore.

Specimen #	Month	Day/Night	Stage	Station	Depth	Net/Mesh Size
47A$_2$	February	Day	1	A	0 – 25 m	Tucker/760 µm
55A$_1$	March	Day	2	C	0 – 25 m	Bongo/220 µm
67A$_1$	March	Day	1	B	0 – 25 m	Bongo/220 µm
73A$_3$	March	Night	1	B	0 – 25 m	Tucker/760 µm
75A$_1$	March	Night	1	B	0 – 25 m	Bongo/220 µm

All five larvae identified were confirmed to be in the family Geryonidae based on their large size and overall morphological characteristics. Measurements of larvae were compared to the work of Stuck et al. (1992) and the measurements they report for *C. fenneri* and *C. quinquedens*. Positive identification to species level proved inconclusive using this method. However, it was determined that all specimens found are of the

species *C. fenneri* based on the absence of the dorsolateral spine on the 5th somite of the abdomen (Table 8).

Table 8: Measurements (mm) of morphological features compared with the findings of Stuck et al. (1992). 'f' = characteristic of C. fenneri; 'q' = characteristic of C. quinquedens; 'i' = indeterminate. A '–' indicates that feature was missing or damaged.

Specimen	$47A_2$	$55A_1$	$67A_1$	$73A_3$	$75A_1$	*C. fenneri*	*C. quinquedens*
Morphological Feature							
Total Length Z1	0.948 (f)			1.278 (q)		CL = 0.95-1.08	CL = 1.05-1.20
Total Length Z2		1.239 (i)				CL = 1.10-1.37	CL = 1.10-1.40
Dorsal Spine Length Z1	1.325 (q)			1.307 (q)	1.163 (i)	DSL = 1.05-1.15	DSL = 1.18-1.38
Dorsal Spine Length Z2		1.571 (i)				DSL = 1.20-1.62	DSL = 1.20-1.53
Spine Width Z1	1.308 (f)					SW = 1.55-1.78	SW = 1.73-2.10
Spine Width Z2		1.925 (i)				SW = 1.80-2.18	SW = 1.95-2.35
Total Spine Length Z1	2.698 (i)			2.733 (i)	2.3 (f)	TSL = 2.50-2.90	TSL = 2.65-3.06
Total Spine Length Z2		3.373 (i)				TSL = 3.01-3.62	TSL = 3.11-.352
Presence of dorsolateral spine on 5th abdominal somite	N	N	N	N	N	N	Y

Densities for *C. fenneri* at each station as well as per month were low overall. Across the entire sampling period, a mean density of 0.07 (± 0.03) 1000 m^{-3} was found. Mean densities per month were 0.05 (± 0.05) 1000 m^{-3} in February and 0.38 (± 0.21)1000 m^{-3} for March. Per station, mean densities were 0.02 (± 0.02)1000 m^{-3} at Station A, 0.11 (± 0.07)1000 m^{-3} for at Station B, and 0.10 (± 0.10)1000 m^{-3} at Station C (Table 9). Density calculations per month, station, net type, diel period, and depth category are referenced in Appendices A – E.

Table 9: Densities (1000 m^{-3}) of *C. fenneri* per year, month, and station

	Mean Densities (1000 m^{-3})
Yearly	0.07 (± 0.03)
February	0.05 (± 0.05)
March	0.38 (± 0.21)
Station A	0.02 (± 0.02)
Station B	0.11 (± 0.07)
Station C	0.10 (± 0.10)

5.4 Discussion

The occurrence of *Chaceon fenneri* larvae in the samples was expected to be much higher than that found. As females are known to ascend the continental slope to waters less than 400 m deep to release their eggs, and knowing that their larvae ascend to surface waters after hatching (Kelly et al. 1982), it would be expected to find larvae in abundance especially in the 0 – 25 m depth range. In particular, at the deepest station, Station C, which is approximately 300 m deep, it was expected that larvae would be found in the surface waters. Although no statistically significant pattern was able to be detected, the occurrence of zoeal stages 1 and 2 found from the February and March

samples does coincide with known spawning times of females (Erdman and Blake 1988a; Erdman et al. 1990) and suggests that densities of larvae are highest in these months.

Timing between larval stages is not documented making it difficult to predict exactly when later stage zoea and megalops would occur in the plankton. However, as stage 1 and 2 zoea were seen from the February and March samples, these later stage larvae would be expected to be seen in March, April and May. However, this was not observed in this study. This infrequent occurrence of *C. fenneri* larvae from this study begs two important questions: 1.) Why were the larvae in such low abundances? and, 2.) Why were later stage larvae absent from samples? Though further research may help to answer these questions, some speculation can be made.

Absence of zoea and megalops from the spring months may be explained by their descent in the water column in preparation for settlement as juveniles on the deeper slope. Geryonid crabs are known to begin larval development in the surface waters and speculated to sink as megalopa, in similar behavior to other brachyuran crabs, in an effort to find suitable habitat (Kelly et al. 1982). In addition, juvenile geryonid crabs have been found at the deeper ranges of the adult habitats which also suggests that megalops are sinking to depth prior to molting to the juvenile stage in preparation for migration to adult habitats (Kelly et al. 1982; Manning 1990). However, this would suggest a potential presence of later stage zoea from the 0 – 200 m samples but no *C. fenneri* larvae were found in any samples from that depth range.

Just one other study, conducted in the eastern GOM, has looked for the occurrence of *C. fenneri* larvae in the plankton. In that study, Perry et al. (1991) also reported low abundances of larvae, finding only 11 specimens during their entire

sampling period. In addition, they found only Stage 1 and Stage 2 zoea with one occurrence of a Stage 2 zoea from a bottom tow (Perry et al. 1991). The remainder of the zoea they found, similar to the current study, were sampled from the 0 – 25 m depth range. The Perry et al. (1991) study sampled the same spring months as this study, excluding April, and similar results also showed the larvae were found in the months of February and March only.

The adult red crab, *C. quinquedens*, overlaps only slightly in bathymetric distribution with *C. fenneri* (Lindberg and Lockhart 1993), though their larvae occupy the same depth in the water column as was shown by the Perry et al. (1991) study. However, no *C. quinquedens* larvae were found in the samples from this study. It is possible that identification of *C. quinquedens* could have been confused with *C. fenneri* during the current study, however, using the literature and larval descriptions, it was determined that the specimens found were not *C. quinquedens*.

Kelly et al. (1982), in a study on the red crab, concluded that the dispersal for geryonid larvae can be high depending on current velocities and vertical migration of the early stage larvae. As *C. fenneri* larvae are released by females on the continental slope and dispersed directly into the Florida Current where they ascend to surface waters, they are automatically dispersed in the current and are most likely to locations north of their parent populations. This high dispersal potential would mean that larvae spawned in southeastern Florida are being transported to northern parent populations during larval development. However, the profitable fishery for this crab in southeastern Florida suggests that stock populations exist here to support the fishery. If all larvae are

dispersing in the current, then local populations must be being supplied by some southern populations and it would still be expected to find later stage zoea in the water column.

This species high dispersal potential has great implications for fisheries management. It is possible that parent populations from outside the managed zones are supplying populations to the north. In order to be effective, local management must extend to other areas to encompass all stock populations for protection. Further investigations into the population ecology, life history and dispersal patterns of *C. fenneri* will help provide much needed information for this species and for fisheries managers. With this knowledge, this species, which has the potential of growing into a much bigger fishery, can maintain sustainability.

6.0 *Menippe mercenaria* (stone crab)

6.1 Introduction

Menippe mercenaria makes up the third largest crustacean fishery in Florida following only the blue crab and spiny lobster (FFWCC 2010). Yet, this species is the least researched of all the commercially important crabs from Florida waters. As seen with other managed fisheries, there is minimal data on larval distribution and population enhancement. With increasing catch rates and demand on the fishery, knowledge of larval patterns and life history parameters can be a useful aid to managers.

6.1.1 Fishery

Management of *M. mercenaria* is regulated by the Gulf of Mexico Fishery Management Council (GOMFMC). This fishery is unique because only the claws of the animal are harvested while the crab is returned by fishermen to the ocean where it is available for reharvesting after regeneration through molting (Muller et al. 2006). An additional benefit to the sustainability of this species is that most females complete at least one spawning season prior to their claws reaching legal size (Muller et al. 2006). However, even with the animals being returned to the water, an increase in fishing pressure shows that the fishery is not sustainable. Total traps have increased dramatically since 1963 when the fishery boasted a mere 1500 traps in the water compared to the 2001-2002 season which reported 1.6 million. Management agencies deem the fishery as overfished due to trap numbers tripling since the 1990 season. This is further supported by models which show that the increased numbers of traps compared to recruitment of the juveniles into the population will cause the fishery to decline (Muller et al. 2006). Current regulations to the fishery include: season restrictions with

allowable harvesting from October 15-May 15, minimum claw size, regulated on-board treatment of crab and daily catch limits (Muller et al. 2006).

6.1.2 Life History

Menippe mercenaria are a xanthid crab in the family Menippidae. They are found from North Carolina to the Bahamas and Caribbean and into the Gulf of Mexico and are known to inhabit the waters along the entire coastline of Florida and throughout the Florida Keys (Lindberg and Marshall 1984). Adult *M. mercenaria* typically inhabit shallow areas with females found in sea grass beds and males farther offshore but exhibiting migration patterns onshore for mating (Porter 1960).

Females can spawn up to six times from one mating event and each spawning can produce from 350,000 up to a million eggs which is thought to be related to size of female (Lindberg and Marshall 1984). Spawning has been observed year round in southern Florida with a general season from March to November and a peak in the warmest months of August and September (Lindberg and Marshall 1984; Muller et al. 2006). Porter (1960) observed development from hatching to the juvenile stage to occur in 27 days with development consisting of five zoeal and one megalopa stage. Development between each stage takes from three to six days (Porter 1960). Peak larval abundance is expected between August and October.

6.2 Materials and Methods

6.2.1 Species Identification

Samples were analyzed for occurrence of Xanthid crabs which were identified to species level and staged using the larval description from Porter (1960) and Kurata

(1970). Analysis was conducted using an Olympus SZX7 stereomicroscope fitted with a 1.5x objective. Imaging and measuring of species was done using a 3.3 MPX camera attached to the microscope and transferred to a PC with Rincon Image Analysis Software. Overall morphology of the telson, abdomen, rostral spine and antenna, as well as overall size, was used as a key identifier to the genus level. For positive identification to the species level, zoea were analyzed for the presence of a mid-ventral spine on abdominal segments 3, 4, and 5. The megalopa stage was identified by comparing carapace length (CL) to values from the literature and by analyzing rostral spine morphology which shows a centrally depressed rostrum with pointed angles (Figure 28). Stage determination relied exclusively on maxilliped exopod setation, where maxilliped 1 bears 4 plumose setae in Stage 1, 10 plumose setae in Stage 2, 13 – 14 plumose setae in Stage 3 and 17 – 18 plumose setae in Stage 4 (Porter 1960).

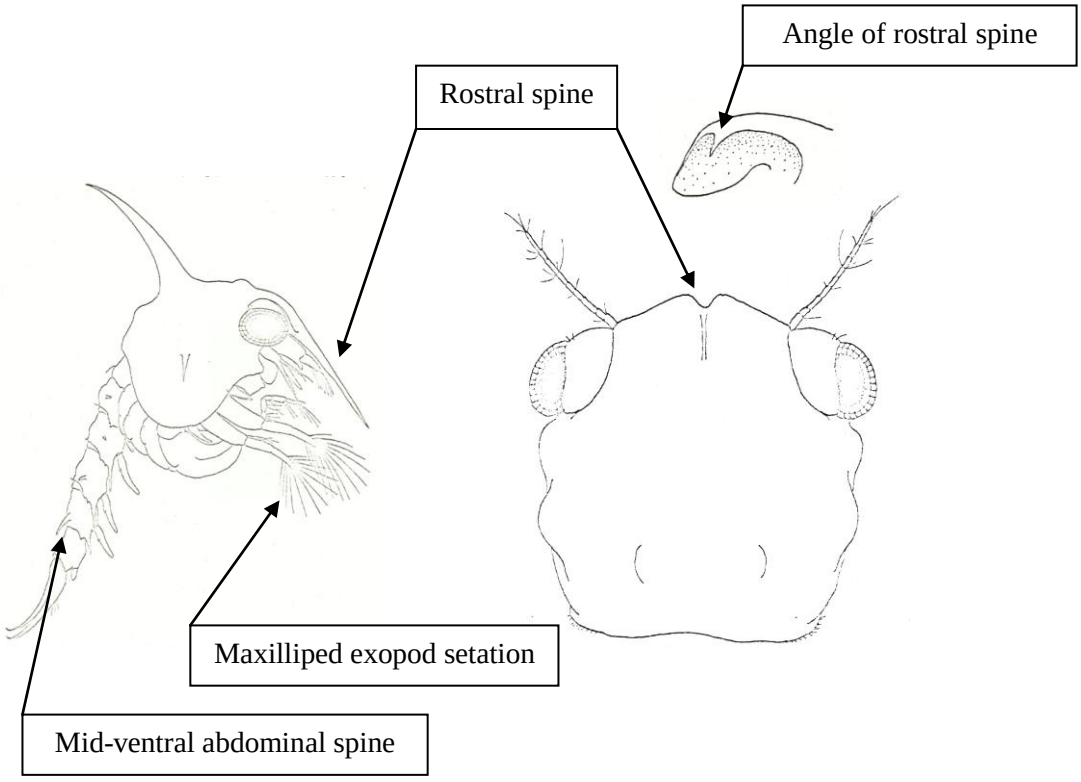

Figure 28: Key morphological features of *Menippe mercenaria* zoea and megalopa. Adapted from Porter (1960) and Kurata (1970).

6.3 Results

M. mercenaria were found in very low abundance throughout the sampling period and overall low densities did not allow for statistical analysis of temporal and spatial patterns. However, basic descriptive statistics were run for average densities (1000 m^{-3}) ± 1 standard error of the mean (± SEM). A total of seven megalopa were identified from the samples. No zoeal stage individuals were identified. Four megalops were found from station A and three from station B. No larvae were identified from station C. Five megalops were collected during daytime samples and two during the nighttime samples.

Five of the seven megalops came from the upper 25 m samples and two were taken from the 0-200 m depth range samples. All megalops identified were collected in the Tucker trawl nets (Table 10).

Table 10: *Menippe mercenaria* megalops identified from samples. Station A = inshore, station B = middle.

Specimen #	Month	Day/Night	Station	Depth Range	Net/Mesh Size
187A$_{21}$	May	Day	A	0 – 25 m	Tucker/760 µm
211B$_{2}$	July	Day	B	0 – 200 m	Tucker/760 µm
223A$_{2}$	July	Night	B	0 – 25 m	Tucker/760 µm
233A$_{4}$	July	Night	A	0 – 25 m	Tucker/760 µm
235B$_{11}$	July	Day	A	0 – 200 m	Tucker/760 µm
					Tucker/760 µm
259A$_{4}$	September	Day	B	0 – 25 m	Tucker/760 µm
287A$_{2}$	September	Day	A	0 – 25 m	Tucker/760 µm

For the entire year's samples, a mean density of 0.08 (± 0.03) 1000 m^{-3} was found. Mean densities (1000 m^{-3}) per month were 0.05 (± 0.05) in May, 0.34 (± 0.16) in July, and 0.14 (± 0.10) for September. Per station, mean densities (1000 m^{-3}) were 0.07 (± 0.04) at Station A, and 0.12(± 0.06) at Station B. No megalops were collected at Station C (Table 11). Density calculations per month, station, net type, diel period, and depth category are referenced in Appendices A – E.

Table 11: Densities (1000 m^{-3}) of *C. fenneri* per year, month, and station

	Mean Densities (1000 m^{-3})
Yearly	0.08 (± 0.03)
May	0.05 (± 0.05)
July	0.34 (± 0.16)
September	0.14 (± 0.10)
Station A	0.07 (± 0.04)
Station B	0.12 (± 0.06)
Station C	0

6.4 Discussion

Low densities of *Menippe mercenaria* were not unexpected from the sampling area. Xanthid crabs, while exhibiting use of nearshore processes for transport away from parent populations for development, are not known to use the major offshore currents, like the Florida Current, as dispersal mechanisms (Krimsky et al. 2009). Like estuarine crabs, xanthid crabs do exhibit active vertical movement in the water column and their zoea have been observed in the surface layers, an advantage assumed to keep them from being swept far offshore (Krimsky et al. 2009). The low overall densities seen from this study, therefore, are not surprising but beg the question as to why any *M. mercenaria* larvae were found in samples.

Low overall densities might be explained by looking at salinity and temperature ranges recorded during the sampling period. Temperature ranges from this study compared to previous studies fluctuated greatly and reached the lower limit of known optimal range. Salinity ranges recorded were higher than those seen from previous laboratory rearing studies (Table 12). As with *C. fenneri*, it is possible that *M. mercenaria* larvae do not reside in the higher temperature waters but stay in areas better suited for optimal development.

Table 12: Optimal salinity and temperature ranges for *M. mercenaria* larvae from laboratory rearing experiments compared to the current study.

Study	**Date**	**Optimal Salinity (‰)**	**Optimal Temperature (˚C)**	**Lab/In Situ**
Kah-Sin Ong et al.	1970	30-35	30	Lab
Brown et al.	1992	31	28	Lab
		Salinity (‰) Range	**Temperature (˚C) Range**	
Current Study (Recorded CTD Data)	2007	35.18-36.35	8.06-30.06	In situ

Additionally, it can be speculated that those specimens found in the Florida Current are accidental. Lack of previous research regarding dispersal patterns in combination with the low occurrences seen from this study, allow only inferences and speculations. However, it is surmised that those individuals found will not be recruited back to parent populations, but, instead, lost to the current. Further nearshore sampling

will help in determining where densities are highest and where larvae reach maturity before settling into parent populations.

Because larvae were only observed in the warmer summer months, year round spawning cannot be confirmed in these waters. However, the highest mean density observed was during the July cruise which supports the known spawning times for this species. Increased spatial and temporal sampling will help determine where *M. mercenaria* larvae reside before settling and likely shed light on their dispersal patterns.

7.0 Conclusion

Although the larvae of *Menippe mercenaria* and *Chaceon fenneri* were not seen in high enough densities to be statistically analyzed, an overall pattern did exist for these species, as well as for *Callinectes sapidus*, showing peaks in densities associated with the peak spawning time for each species. While higher densities of the larvae of commercially important crabs were expected to be seen in the Florida Current indicating its use as a dispersal mechanism, this was not evident during this study. This low occurrence of larvae was unexpected from the samples and is particularly puzzling for *C. fenneri* which is presumed to release their eggs directly in the FC. Increased study of female spawning patterns of this species as well as for those of the blue crab and stone crab will provide researchers with a better understanding of early life history patterns and dispersal mechanisms.

The absence of larvae from the April samples was a common pattern seen among all three species observed. As mentioned in relation to blue crab, it is likely that the processes of the FC during this sampling period, especially those observed during April, may be the cause for their absence from the samples during this month's cruise. A more targeted sampling study and increased monitoring of the tidal flows and currents will help to determine the effect of larval distribution during these physical events.

Most notably, this study's results indicate that the larvae of these species do not use the Florida Current as a means of long-distance dispersal. If this were the case, higher densities of larvae, particularly those of *C. fenneri* and *C. sapidus*, would have been observed during sampling. As mentioned, high densities of *M. mercenaria* larvae were not expected and it is possible that those that were found were transported from

areas like the Florida Keys and were likely captured in the FC and removed from local parent populations. This possibility exists for *C. sapidus* as well. Perhaps all the specimens found in the samples are those that were lost to the current and swept away from parent populations. Perhaps those that are able to exhibit active vertical migration keeping them shoreward, are those that will successfully repopulate the stock.

7.1 Implications and Future Research

While a more in-depth and expanded study will offer a better understanding of the results found here, it can be inferred that since these larvae do not appear to be dispersing long distances, self-recruitment is most likely the mechanism by which local stocks are being repopulated. Local recruitment, while reducing the risk of larvae being lost to the current, does not offer the benefit of genetic diversity to stocks. However, since all three fisheries are maintaining their populations in the face of increased fishing pressure, local genetic exchange may be a sufficient mechanism for sustaining local populations.

Recent research using "elemental fingerprinting" as a means of tracking larvae through settlement is helping to shed light on larval dispersal patterns (Becker et al. 2007). While this method of applying chemical signatures to a species has its challenges for invertebrates, advances are being made that may soon allow this tracking method to be successful and would certainly help bring the current research on recruitment of crustacean fisheries to an advanced level. In the short-term, nearshore sampling, sampling within and at mouths of estuaries, more frequent sampling events as well as sampling that incorporates tidal periods, light-dark cycles and lunar cycles, will help to offer a bigger picture of larval patterns in the southeast Florida region.

The overall lack of knowledge about the local Florida populations of crab fisheries and by what mechanisms they are being stocked is cause for great concern. This research aimed to gather the necessary baseline data for these species in this area. Expanded, novel, and targeted research efforts of the local crab fishery populations will help provide a bigger picture of the species' life histories and will aid in more effective management.

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Appendix A: Total abundance (*n*) and mean densities ± 1 SEM (1000 m^{-3}) of *Callinectes sapidus*, *Chaceon fenneri*, and *Menippe mercenaria* larvae from all samples across all monthly sampling events.

Monthly Sampling	Species	Total (*n*)	Mean Density ± 1 SEM (1000 m^{-3})
All months			
	Callinectes sapidus	61	0.77 (± 0.20)
	Chaceon fenneri	5	0.07 (± 0.03)
	Menippe mercenaria	7	0.08 (± 0.03)
February			
	Callinectes sapidus	4	0.58 (± 0.28)
	Chaceon fenneri	1	0.05 (± 0.05)
	Menippe mercenaria	-	-
March			
	Callinectes sapidus	1	0.07 (± 0.07)
	Chaceon fenneri	4	0.38 (± 0.21)
	Menippe mercenaria	-	-
April			
	Callinectes sapidus	-	-
	Chaceon fenneri	-	-
	Menippe mercenaria	-	-
May			
	Callinectes sapidus	33	2.75 (± 1.08)
	Chaceon fenneri	-	-
	Menippe mercenaria	1	0.05 (± 0.05)
July			
	Callinectes sapidus	14	1.18 (± 0.59)
	Chaceon fenneri	-	-
	Menippe mercenaria	4	0.34 (± 0.16)
September			
	Callinectes sapidus	8	0.79(± 0.35)
	Chaceon fenneri	-	-
	Menippe mercenaria	2	0.14 (± 0.10)
November			
	Callinectes sapidus	1	0.07(± 0.07)
	Chaceon fenneri	-	-
	Menippe mercenaria	-	-

Appendix B: Total abundance (*n*) and mean densities ± 1 SEM (1000 m^{-3}) of *Calllinectes sapidus*, *Chaceon fenneri*, and *Menippe mercenaria* larvae per net type across all monthly sampling events.

Monthly Sampling	Species	Total (*n*)		Mean Density ± 1 SEM (1000 m^{-3})	
		Bongo	Tucker	Bongo	Tucker
All months					
	Callinectes sapidus	15	46	0.79 (± 0.26)	1.01 (± 0.38)
	Chaceon fenneri	3	1	0.11 (± 0.06)	0.03 (± 0.02)
	Menippe mercenaria	-	7	0.06 (± 0.04)	0.09 (± 0.04)
February					
	Callinectes sapidus	3	1	1.005 (± 0.52)	0.01 (± 0.10)
	Chaceon fenneri	-	1	-	0.01 (± 0.01)
	Menippe mercenaria	-	-	-	-
March					
	Callinectes sapidus	-	1	-	0.13 (± 0.13)
	Chaceon fenneri	3	1	0.766 (± 0.35)	0.12 (± 0.12)
	Menippe mercenaria	-	-	-	-
April					
	Callinectes sapidus	-	-	-	-
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	-
May					
	Callinectes sapidus	8	25	2.515 (± 1.23)	2.99 (± 1.85)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	1	-	0.09 (± 0.09)
July					
	Callinectes sapidus	3	11	0.739 (± 0.38)	1.63 (± 1.12)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	4	-	0.68 (± 1.30)
September					
	Callinectes sapidus	1	7	0.508 (± 0.51)	1.07 (± 0.48)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	2	-	0.29 (± 0.19)
November					
	Callinectes sapidus	-	1	-	0.13 (± 0.132)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	--

Appendix C: Total abundance (*n*) and mean densities ± 1 SEM (1000 m^{-3}) of *Calllinectes sapidus*, *Chaceon fenneri*, and *Menippe mercenaria* larvae per station across all monthly sampling events. St. A = inshore, St. B = Middle, St. C = offshore.

Monthly Sampling	Species	Total (*n*)			Mean Density ± 1 SEM (1000 m^{-3})		
		St. A	St. B	St. C	St. A	St. B	St. C
All months							
	Callinectes sapidus	46	13	2	1.63(± 0.53)	0.58(± 0.18)	0.08(± 0.08)
	Chaceon fenneri	1	3	1	0.02(± 0.02)	0.11(± 0.07)	0.10(± 0.10)
	Menippe mercenaria	4	3	-	0.07(± 0.04)	0.12(± 0.06)	-
February							
	Callinectes sapidus	2	2	-	0.64(± 0.51)	0.74(±0.49)	-
	Chaceon fenneri	1	-	-	0.12(± 0.12)	-	-
	Menippe mercenaria	-	-	-	-	-	-
March							
	Callinectes sapidus	1	-	-	0.17(± 0.17)	-	-
	Chaceon fenneri	-	3	1	-	0.77(±0.40)	0.68(±0.34)
	Menippe mercenaria	-	-	-	-	-	-
April							
	Callinectes sapidus	-	-	-	-	-	-
	Chaceon fenneri	-	-	-	-	-	-
	Menippe mercenaria	-	-	-	-	-	-
May							
	Callinectes sapidus	30	3	-	6.29(± 2.20)	0.59(±0.30)	-
	Chaceon fenneri	-	-	-	-	-	-
	Menippe mercenaria	1	-	-	0.12(± 0.12)	-	-
July							
	Callinectes sapidus	11	3	-	2.23 (±1.37)	0.73(±0.39)	-
	Chaceon fenneri	-	-	-	-	-	-
	Menippe mercenaria	2	2	-	0.42(±0.27)	0.44(±0.31)	-
September							
	Callinectes sapidus	1	5	2	0.31(± 0.31)	1.43(±0.76)	0.47(± 0.47)
	Chaceon fenneri	-	-	-	-	-	-
	Menippe mercenaria	1	1	-	0.18(± 0.18)	0.18(±0.18)	-
November							
	Callinectes sapidus	1	-	-	0.17(± 0.17)	-	-
	Chaceon fenneri	-	-	-	-	-	-
	Menippe mercenaria	-	-	-	-	-	-

Appendix D: Total abundance (*n*) and mean densities ± 1 SEM (1000 m^{-3}) of *Calllinectes sapidus*, *Chaceon fenneri*, and *Menippe mercenaria* larvae per diel period across all monthly sampling events.

Monthly Sampling	Species	Total (*n*)		Mean Density ± 1 SEM (1000 m^{-3})	
		Day	Night	Day	Night
All months					
	Callinectes sapidus	29	32	0.69 (± 0.21)	1.23 (± 0.45)
	Chaceon fenneri	3	2	0.07 (± 0.05)	0.06 (± 0.05)
	Menippe mercenaria	5	2	0.08 (± 0.03)	0.07 (± 0.05)
February					
	Callinectes sapidus	2	2	0.426 (± 0.52)	0.740 (± 0.10)
	Chaceon fenneri	1	-	0.08 (± 0.08)	-
	Menippe mercenaria	-	-	--	-
March					
	Callinectes sapidus	-	1	-	0.165 (± 0.132)
	Chaceon fenneri	2	2	0.44 (± 0.31)	0.45 (± 0.32)
	Menippe mercenaria	-	-	-	-
April					
	Callinectes sapidus	-	-	-	-
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	-
May					
	Callinectes sapidus	8	25	0.947 (± 1.23)	5.463 (± 1.85)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	1	-	0.08 (± 0.08)	-
July					
	Callinectes sapidus	11	3	1.522 (± 0.38)	0.675 (± 1.12)
	Chaceon fenneri	-	-	-	
	Menippe mercenaria	2	2	0.22 (± 0.15)	0.52 (± 0.35)
September					
	Callinectes sapidus	7	1	1.11 (± 0.51)	.311 (± 0.48)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	2	-	0.24 (± 0.16)	-
November					
	Callinectes sapidus	1	-	-	0.110 (± 0.132)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	-

Appendix E: Total abundance (*n*) and mean densities ± 1 SEM (1000 m^{-3}) of *Calllinectes sapidus*, *Chaceon fenneri*, and *Menippe mercenaria* larvae per depth category across all monthly sampling events. Category 1 = Upper 25 m, Category 2 = Entire water column.

Monthly Sampling	Species	Total (*n*)		Mean Density ± 1 SEM (1000 m^{-3})	
		Category 1	Category 2	Category 1	Category 2
All months					
	Callinectes sapidus	41	20	1.01 (± 0.37)	0.79 (± 0.28)
	Chaceon fenneri	5	-	0.14 (± 0.07)	-
	Menippe mercenaria	5	2	0.11 (± 0.05)	0.04 (± 0.03)
February					
	Callinectes sapidus	2	2	0.361 (± 0.27)	0.742 (± 0.50)
	Chaceon fenneri	1	-	0.098 (± 0.098)	-
	Menippe mercenaria	-	-	-	-
March					
	Callinectes sapidus	-	1	0.132 (± 0.132)	-
	Chaceon fenneri	4	-	0.886 (± 0.39)	-
	Menippe mercenaria	-	-	-	-
April					
	Callinectes sapidus	-	-	-	-
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	--
May					
	Callinectes sapidus	8	25	3.621 (± 1.92)	1.885 (± 1.04)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	1	-	0.09 (± 0.09)	-
July					
	Callinectes sapidus	11	3	0.593 (± 0.37)	1.773 (± 1.11)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	2	2	0.41 (± 0.28)	0.27 (± 0.18)
September					
	Callinectes sapidus	7	1	1.377 (± 0.63)	0.204 (± 0.20)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	2	-	0.29 (± 0.19)	-
November					
	Callinectes sapidus	1	-	-	1.323(± 0.13)
	Chaceon fenneri	-	-	-	-
	Menippe mercenaria	-	-	-	-